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M.Sc. Environmental science in Europe – Soil, Water and Biodiversity

MASTER THESIS

The impact of meteorological conditions and spatial distribution on the PM10 and PM2,5 concentration in Vienna.

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Abstract

Ambient air pollution is one of the biggest threats to human health over the whole world. One of the most important forms of ambient air pollution is particulate matter (PM); within this, the PM2,5 and PM10 concentrations are analysed. The concentrations of PM are impacted by meteorological conditions as well as local variations. This research aims to look at to what extent weather conditions and spatial distribution affect the PM10 and PM2,5 concentrations, within the city of Vienna, Austria. The results show that certain weather conditions like wind direction, wind speed, cyclonic conditions, precipitation, and humidity have a significant impact on the PM10 and PM2,5 concentrations. Furthermore, analysis has been done on the effects of spatial distribution on the PM concentrations; the results show differences in PM concentrations near green spaces compared to more dense urban areas with busy roads and built-up areas. These mobile measurements were done in the winter months and the summer months to see if there is a difference in the PM concentrations with the seasons. The mobile measurements indicate that the location of the measurements is highly correlated to the PM concentrations. The results show that the combination of meteorological conditions and the spatial distribution of PM affects the concentrations significantly. When looking at the PM10 concentrations, the results show that wind direction, cyclonic or anticyclonic conditions at 925hPa and at 500hPa and humidity conditions have a significant impact on the PM10 concentrations. When looking at the PM2,5 concentrations the results show only wind direction and humidity conditions have a significant impact on the concentrations. The results show that the PM10 and PM2,5 concentrations are impacted by the characteristics of their surroundings.

Luftverschmutzung ist weltweit eine der größten Bedrohungen für die Gesundheit des Menschen. Eine der wichtigsten Formen der Luftverschmutzung ist Feinstaub (PM). Daher wurden für diesen Bericht die PM2,5- und PM10-Konzentrationen analysiert. Die Konzentrationen an PM sind sowohl durch Wetterbedingungen als auch durch lokale Unterschiede beeinflusst. Diese Studie zielt darauf hin zu untersuchen inwieweit Wetterbedingungen und räumliche Verteilung einen Effekt auf die Konzentrationen von PM2,5 und PM10 in Wien, Österreich hat. Die Ergebnisse zeigen, dass gewisse Wetterbedingungen wie Windrichtung, Windgeschwindigkeit, zyklonale Bedingungen, Niederschlag, und Luftfeuchtigkeit einen signifikanten Einfluss auf PM10- und PM2,5-Konzentrationen haben. Des Weiteren wurden Analysen bezüglich des Einflusses der räumlichen Verteilung auf die PM-Konzentrationen durchgeführt. Die Ergebnisse weisen Unterschiede in den PM-Konzentrationen im Vergleich von begrünten Flächen und urbaneren Gegenden mit viel befahrenen Straßen und Ballungsräumen auf. Es wurden sowohl in den Winter- als auch den Sommermonaten mobile Messungen durchgeführt, um zu sehen ob ein jahreszeitlicher Unterschied bei den PM-Konzentrationen auftritt. Diese mobilen Messungen deuten darauf hin, dass der Standort der Messungen stark mit den

PM-Konzentrationen korreliert. Die Ergebnisse zeigen, dass die Kombination von Wetterereignissen und die räumliche Verteilung von PM die Konzentrationen signifikant beeinflusst. Bei Betrachtung der PM10-Konzentrationen sieht man in den Ergebnissen, dass Windrichtung, zyklonale oder antizyklonale Bedingungen bei 925 hPa und 500 hPa, und Luftfeuchtigkeit einen signifikanten Einfluss auf PM10-Konzentrationen haben. Wenn man PM2,5-Konzentrationen betrachtet, erkennt man anhand der Ergebnisse, dass nur die Windrichtung und die Luftfeuchtigkeit einen signifikanten Einfluss auf diese haben. Die Ergebnisse zeigen auf, dass sowohl die PM10- als auch die PM2,5-Kozentrationen von den äußerlichen Bedingungen ihrer Umgebung beeinflusst sind.

Key words: air pollution, particulate matter, meteorological conditions, spatial distribution

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1. Introduction

Ambient air pollution is a significant threat to human health, our surrounding environment and the biodiversity on the planet (Kim, Kabir and Kabir, 2015). The main problem is the fact that air pollutants can have significant impacts, even when exposure occurs in small quantities (Welty and Zeger, 2005). The leading cause is related to the air pollutants that are emitted as primary anthropogenic sources (Brimblecombe and Maynard, 2000; Akimoto, 2003; Oke *et al.*, 2017). Ambient air pollution is a problem that affects rural areas and cities. However, the impact of ambient air pollutants is mostly felt within cities. Due to the density of populations and their proximity to large pollutants as well as the complex intermingling of the emissions from various sources. This, combined with the specific features of urban meteorology has led to the effects of air pollution having a more significant relevance within cities (Van Dingenen *et al.*, 2004; Zheng, Liu and Hsieh, 2013; Oke *et al.*, 2017). Currently, 55% of the world population lives in urban areas. This is expected to increase to 68% by 2050. With a gradual shift from rural to urban areas as well as the expected increasing world population, this number is only expected to grow even further in the future (United Nations, Department of Economic and Social Affairs and Population Division, 2019). This would mean that ambient air pollution would have a higher impact on more people everywhere.

Ambient air pollution is an issue that affects developed and developing countries. Even with developing countries making a shift from polluting industries to cleaner energy resources, there are still many sources that reduce the air quality. It would be expected that in the future new technologies, innovations and developments would reduce the air pollution concentrations. However, currently, the ambient air pollution concentrations in many countries are not decreasing as much as they should (World Health Organization, 2005). To mitigate the levels of air pollutions, the World Health Organisation (WHO) has set specific guidelines that should create cleaner air for people to breathe. These guidelines should provide governments around the world with good restricting values for what is considered to be a healthy outdoor environment to live in. However, according to the WHO, currently even with these guidelines, around 91% of the world's population still lives in places where the air quality levels exceed these limits (World Health Organization, 2016, 2018). In many places, these guidelines are not always followed, and the limits are often exceeded, this occurs in developing and developed countries alike (World Health Organization, 2005, 2018).

Local air pollutants are closely linked to global air systems and can even affect global climate change. Due to the different aerosol particles formed in air pollutants the incoming solar radiation is scattered or absorbed, this also indirectly influences cloud processes and thus affects the climate. Furthermore, certain air pollutants like CO_2 are well-known greenhouse gasses that cause the greenhouse effect (Akimoto, 2003; Pirjola *et al.*, 2017). The indirect effects of ambient air pollutants are of high importance to human health. Due to the connection between air pollutants and climate change, the

present day air pollutants will also affect human wellbeing to a greater extent into the future , with dire consequences (World Health Organization, 2005; Bytnerowicz, Omasa and Paoletti, 2007). Locally emitted air pollutants do not only cause a local effect. Due to meteorological conditions, air pollutants can be transported large distances and cause effects at different locations. Long-range transportation of air pollutants will influence regional air quality downwind of the source (Yienger *et al.*, 2000; Huntrieser *et al.*, 2005). Ambient air pollutant concentrations can thus differ much within different locations. However, at the same location, the concentrations can also vary much due to meteorological conditions, unfavourable meteorological conditions may cause accumulation or degradation of air pollutants (Oke *et al.*, 2017).

Ambient air pollutants occur in many different forms, with various sources and different impacts on their surrounding environment (Oke *et al.*, 2017). Particulate matter (PM), is one of the most interesting pollutants to look at, the reason being is that PM affects more people than any other pollutant (Hofman *et al.*, 2013; World Health Organization, 2016). PM is especially a problem within urban areas; this is due to a positive correlation that has generally been found between PM concentrations and increased urbanization (Weijers *et al.*, 2004). As urbanisation is expected to increase in the future, PM concentrations are also likely to increase.

Within this research, the focus will be on PM concentrations and the effect of meteorological conditions on the concentrations as well as the spatial distribution of PM concentrations. This research will focus on the city of Vienna in Austria. The meteorological conditions will be analysed by using the weather classes database Objektive Wetterlagen Klassifikation, also known as OWLK. The OWLK is a weather classification method that is based on the weather type classification as is defined in Dittmann et al. 1995 as well as Bissolli and Dittmann, 2003 (Dittmann *et al.*, 1995; Bissolli and Dittmann, 2003; Philipp *et al.*, 2010). This weather classification looks at wind direction, cyclonic or anticyclonic conditions at 925hPa and 500hPa and humidity. Furthermore, wind speed and precipitation will be analysed.

1.1. Particulate matter

As discussed, PM is an interesting air pollutant due to the significant effect that it has on people. Even when occurring in low concentrations, PM is known to have lethal effects on the population within urban areas (Neuberger, Rabczenko and Moshammer, 2007). PM pollution has been estimated to contribute to hundreds of thousands of premature deaths across Europe each year as well as millions of premature deaths worldwide (Apte *et al.*, 2018; Chambers and Podstawczyńska, 2019; Lelieveld *et al.*, 2019). Furthermore, PM concentrations are also associated with many acute and subacute health effects (Pope *et al.*, 2016; Zhang *et al.*, 2018). Health effects related to increased levels of PM concentrations are health effects like cardiovascular and respiratory diseases such as asthma, lung cancer and chronic obstruction pulmonary diseases (Merbitz, Fritz and Schneider, 2012).

There are more reasons why PM is an interesting form of air pollution, as it is not just a single air pollutant like carbon dioxide, nitrogen oxides and other air pollutants. PM consists of a complex mixture of different substances; these can be both liquid and solid particles as well as organic and inorganic, that have all been suspended in the air (Hofman *et al.*, 2013). The PM particles are classified and divided into different fractions that are based on their aerodynamic diameter (Ottelé, van Bohemen and Fraaij, 2010; Hofman *et al.*, 2013). Current PM concentrations are divided into three different categories, within this research, two of these categories will be analysed.

The biggest PM particles are known as PM10 or coarse particulate matter, these are PM with a size less than 10 µm in diameter (Calder, 2008). Coarse particulate matter is formed by mechanical disruption, evaporation of sprays, and suspension of dust and can include resuspended dust, coal and fly ash, and metal oxides of crustal elements (Calder, 2008). PM10 particles have significant health effects, as they have the ability to enter the respiratory tracts they have great inflammatory capacities (Pope III and Dockery, 2006; Merbitz, Fritz and Schneider, 2012).

The PM particles with an aerodynamic diameter less than 2,5 µm are known as PM2,5 or fine particulate matter. Fine particulate matter is formed by different chemical reactions: nucleation, condensation, coagulation as well as the evaporation of fog and cloud droplets in which gasses have dissolved and reacted. The PM2,5 particles can be composed of different elements, known elements are: sulphate, nitrate, ammonium, hydrogen ions, organic compounds, metal, as well as water-bound particles (Calder, 2008). It has been found that the smaller the particles are, the deeper they can be transported into the lungs; thus resulting in in more severe health impacts (Hofman *et al.*, 2013). Due to the smaller size, PM2,5 has a greater impact when looking at chronic respiratory diseases than larger PM10 particles. The PM2,5 can cause enhanced cardiovascular mortality in connection with ischemic heart disease, dysrhythmias, heart failure and cardiac arrest (Pope III and Dockery, 2006; Merbitz, Fritz and Schneider, 2012). PM2,5 is also considered to be a part of the PM10 particles (Calder, 2008).

The smallest PM particles are known as PM1 or ultra-fine particulate matter. These particles have an aerodynamic diameter smaller than 1µm. And therefore they are able to enter the bloodstream with a damaging effect on human health (Silli, Salvatori and Manes, 2015). PM1 has been found to be hard to measure in many cases due to the extremely small size (Chambers and Podstawczyńska, 2019). Within this research PM1 will not be annualized due to the fact that the information on the PM1 concentrations is not always available.

PM concentrations fluctuate greatly over time and space due to many different circumstances. The PM concentrations become especially problematic when the concentrations are high, as higher concentrations are more harmful to people (Merbitz, Fritz and Schneider, 2012). As discussed above, the WHO has set up guidelines that should be followed in order to ensure good air quality, they have set up specific guidelines for the PM10 and PM2,5 concentrations. Based on these guidelines, the Austrian

environmental agency has set up specific exceedance threshold concentrations for the PM10 and PM2,5 concentrations (Umweltbundesamt, 2020). Both the Austrian environmental agency and the WHO advises that daily average of PM10 concentration must not exceed 50 $\mu g \cdot m^{-3}$ within a 24-hour average (World Health Organization, 2018; Umweltbundesamt, 2020), exceedance is only permitted 25 times per calendar year. According to the Austrian environmental agency, the annual average must be less than 40 $\mu g \cdot m^{-3}$ (Umweltbundesamt, 2020). However, the WHO advises annual average concentrations should be less than 20 $\mu g \cdot m^{-3}$ for PM10 (World Health Organization, 2018). As for the PM2,5 concentrations the Austrian environmental agency has set the limit for 25 $\mu g \cdot m^{-3}$ as a maximum annual average, the limit value must be observed from the 1st of January 2015 (Umweltbundesamt, 2020). The Austrian environmental agency has no guidelines for a daily threshold for PM2,5. The WHO has set the limits for 25 $\mu g \cdot m^{-3}$ maximum 24-hour average and a 10 $\mu g \cdot m^{-3}$ maximum annual average (World Health Organization, 2018). The WHO is slightly stricter in the values set up for the threshold's concentrations than the Austrian environmental agency.

PM particles can exist as primary pollutants, or they react with other pollutants and create secondary particles (Puxbaum *et al.*, 2004). There are many different sources of PM. In Vienna, the main components for airborne PM concentrations are inorganic and organic components, soot, insoluble mineralic constituents and small water droplets (Laschober *et al.*, 2004). In an urban area like Vienna, Traffic is one of the largest contributors to PM concentrations. Due to vehicular intensity, driving behaviour, and vehicle type and age, the PM can increase. Within urban areas, the building infrastructure, like open areas or connected areas, with high or low infrastructure can affect the distribution of the PM concentrations homogeneously or inhomogeneous throughout an area (Weijers *et al.*, 2004; Oke *et al.*, 2017).

PM concentrations are known to have daily as well as seasonal variations. Generally, lower PM concentrations are measured in summer seasons, and higher PM concentrations are measured in winter seasons (Welty and Zeger, 2005; Rogula-Kozłowska *et al.*, 2014; Wonaschütz *et al.*, 2015). In winter and cold periods, a phenomenon known as temperature inversions occur, which is a situation in which the temperature increases slowly along with height. Due to cooler air masses in combination with a clear sky, the formation of surface temperature inversion is created and this limits the vertical ventilation of a city (Flocas *et al.*, 2009). Temperature inversion is caused by various atmospheric processes; these can be subsidence, fronts, radiation and advection. However, radiation and advection inversion have been found to occur mostly in the course of air pollution episodes throughout the world (Kukkonen *et al.*, 2005). With these temperature inversions, the air mass becomes stabilised. This results in a reduction in mixing and turbulence. The effect of this reduced mixing of the air is that there is a decrease in dilution and deposition. At the same time, there is a coagulation and condensation of trace gasses on pre-existing particles (Janhäll *et al.*, 2006). The conclusion is that temperature inversion causes increased PM concentrations as well as increased other air pollutants (Palarz and Celiński-Mysław, 2017). As nights

and mornings are usually colder than the rest of the day, temperature inversion occurs more intensely earlier on the day (Janhäll *et al.*, 2006). This whole phenomenon occurs more frequently within urban areas than in rural areas (Hauck *et al.*, 2004).

There are different studies that have proven that a variation of meteorological events influence the spatial distribution of PM and with this the local concentration of PM (Putaud *et al.*, 2004; Gupta and Christopher, 2009; Janhäll, 2015). Some of these meteorological events that influence the spatial distribution of the PM particles are seasonal differences, wind direction and speed, cyclicity, precipitation and humidity (Makra *et al.*, 2007; Gupta and Christopher, 2009). When the meteorological conditions are unfavourable, the air pollutants can accumulate and with this severely degrade the air quality within the urban boundary layer (Oke *et al.*, 2017). The weather conditions will thus, worsen or improve the air quality for a given set of emissions (Oke *et al.*, 2017). The changes within the meteorological conditions affect the PM concentration on a small time scale, like hours, but also on a large time scale, like months and through years (Welty and Zeger, 2005; Janhäll, 2015). Within this research, different meteorological events will be analysed to test if they have a significant impact on the PM concentrations in Vienna.

1.2. Wind and particulate matter concentrations

Wind direction and wind speed have been proven many times to have a significant effect on PM concentrations (Merbitz, Fritz and Schneider, 2012; Hofman *et al.*, 2013; Csavinaa *et al.*, 2014). The wind transports the PM particles, this transportation can be short distance (Laschober *et al.*, 2004), but has also been known to cross oceans and continents (Huntrieser *et al.*, 2005; Brandt *et al.*, 2012). Wind direction can have an impact on the PM concentrations of the air mass as the wind transports the pollutants from sources upwind, which can have large effects downwind (Huntrieser *et al.*, 2005). The wind speed is also of high importance as wind speed regulates stagnation, recirculation and ventilation, thus causing either higher or lower PM concentrations (Russo *et al.*, 2016).

1.2.1. Wind direction

Wind direction is of high importance when looking at the PM concentrations. The air mass origin can determine the chemical composition of both the PM10 and PM2,5 particles (Wonaschütz *et al.*, 2015), When upwind sources emit large amount of PM concentrations, these can be picked up by the wind and transported downwind, causing an increase in PM concentrations in locations downwind (Alier *et al.*, 2013; Freutel *et al.*, 2013).

Within Vienna, the air mass is predominantly transported through the Danube valley and under more intense conditions it is also common that the air mass is transported over the hills (Puxbaum *et al.*, 2004). These wind directions in Vienna are frequently from north/western and south/eastern directions (Stohl and Kromp-Kolb, 1994). Within central Europe, it is common that air masses are transported from

westerly wind directions, air masses from eastern wind directions have been found in past studies to be more polluted (Okada and Hitzenberger, 2001; Müller *et al.*, 2004; Wonaschütz *et al.*, 2015).

Air mass origin has been shown to have an influence on the aerosol characteristics, it was found that in Vienna, 60% of the particles that were bigger than 2,5 µm but smaller than 10 µm were emitted from sources within the city, for the particles smaller than 2,5 µm this was 19% (Puxbaum *et al.*, 2004). The other particles had origins outside of the city, or were formed as secondary pollutants due to reactions within the atmosphere (Wonaschütz *et al.*, 2015). Seasonal variation of wind directions has shown to have little influence on the PM2,5 concentrations. The impact on PM10 concentration is slightly higher, due to the large emittance of dust within winter months (Puxbaum *et al.*, 2004).

The wind directions have another great importance on the PM concentrations. Wind directions impact weather conditions. West and north-western winds are associated with bad weather phases, whereas eastern and south-eastern winds are connected to high summer temperatures and low winter temperatures (Hauck *et al.*, 2004). Thus, the wind directions can impact the other meteorological conditions, and with this, indirectly the PM concentrations.

1.2.2. Wind speed

Wind speed has been known to have an effect on the PM concentrations and the spatial distribution of PM concentration (Hofman *et al.*, 2013). The movement of the wind impacts the pollution potential that the PM particles have on their surrounding (Russo *et al.*, 2016). It is known that different flow types of wind have an effect on the PM concentrations; within this research, only wind speed will be analysed, not wind speed patterns. It has been found that wind speed has a different effect on PM10 than on PM2,5. The wind speed tends to increase the PM10 concentrations; this occurs due to the increase in dust, erosion and other ground particles in the atmosphere(Csavinaa *et al.*, 2014; Zhang *et al.*, 2018). The PM2,5 concentrations have been known to gradually decrease with increasing wind speed (Zhang *et al.*, 2018). Other studies suggest that higher wind speed leads to higher dilution of the particles and therefore, to lower measured PM concentrations (Freutel *et al.*, 2013). With the large number of studies performed on the increase of PM concentration due to soil erosion or prediction of dust, it is still found to be a significant challenge to test how much these events impact the PM concentration (Csavinaa *et al.*, 2014). The wind speed, and pollution potential are still dependent on the wind direction. Therefore the wind direction needs to be considered when looking at the wind speed (Freutel *et al.*, 2013).

1.3. Cyclonic and anticyclonic conditions and particulate matter concentrations

Cyclonic and anticyclonic conditions are of importance when looking at PM concentrations and dispersion. It has been found that cyclonic conditions occur less frequent and that anticyclonic conditions predominate over the whole of Europe (Demuzere *et al.*, 2009; Adamek and Ziernicka-Wojtaszek, 2017; Maheras *et al.*, 2019).

When cyclonic conditions occur, the central air pressure is lower than the surrounding environment; they are characterized by low-level convergence as well as ascending air in the system (Adamek and Ziernicka-Wojtaszek, 2017). Due to this, air pollution levels and thus the PM concentrations, are relatively low during the cyclonic condition (Makra *et al.*, 2007).

Under anticyclonic condition, the central air pressure is higher than the surrounding environment; they are characterized by low level divergence and subsiding air. Anticyclonic conditions are known to lead to large-scale subsidence, clear skies, as well as increased surface temperatures (Pope *et al.*, 2016). It has been shown that most unfavourable air quality conditions usually occur during anticyclonic conditions (Adamek and Ziernicka-Wojtaszek, 2017). Thus, in general, the highest PM concentrations occur during anticyclonic conditions (Makra *et al.*, 2007).

Different pressure heights can also affect the impact that the cyclonic or anticyclonic conditions have on the PM concentrations. Within this research the cyclonic and anticyclonic conditions will be analysed at 925hPa and at 500hPa. The geopotential of cyclonic or anticyclonic conditions can differ at different pressure levels, it is expected that the cyclonic and anticyclonic conditions have more impact on the PM concentrations at 500hPa (Philipp *et al.*, 2010; Pope *et al.*, 2016).

1.4. Humidity and particulate matter concentrations

Relative humidity is known to have an effect on PM concentrations(Gupta and Christopher, 2009). The impact of humidity depends on how intense the humidity is. High humidity is often associated with days of rainfall, whereas this is not always the case with mid humidity(Wang *et al.*, 2018). When the humidity is high, due to rainfall, this usually means that the PM concentrations are decreased. However, mid humidity levels are known to enhance the growth of the secondary particles. With this, it can change the size and distribution of particles, as well as create changes in optical properties and it can also modify the scattering efficiencies (Gupta and Christopher, 2009). Due to the higher humidity, aerosol particles can contain more water, changing the PM mass concentrations (Putaud *et al.*, 2004). Increased relative humidity will, therefore, increase the PM concentration, but when increased too much, the humidity levels wash out the PM particles and cause lower PM concentrations (Flocas *et al.*, 2009; Wang *et al.*, 2018). Relative humidity does not only influence the aerosols in the atmosphere but also has an effect on the soil and dust. When studies have looked at the relative humidity it was found that due to high humidity, soil particles and dust particles were not as frequent within the atmosphere, thus causing less dust emissions in the atmosphere (Ravi and D'Odorico, 2005; Csavinaa *et al.*, 2014). As dust emission mostly influences PM10 concentrations, high relative humidity can reduce the PM concentrations (Csavinaa *et al.*, 2014; Lou *et al.*, 2017; Wang *et al.*, 2018). Low relative humidity has been known to increase the PM concentrations, as there is less washout from the atmosphere and the soil and dust is dry too (Wang *et al.*, 2018).

Within this research, humidity will be defined as dry or wet, this determination will be made according to a weighted area mean value of the precipitable water content, looking at the whole atmospheric column, which will be compared to the long -term daily mean (Philipp *et al.*, 2010).

1.5. Precipitation and particulate matter

Precipitation intensity is known to impact the PM concentrations to a certain extent (Mircea, Stefan and Fuzzi, 2000; Barmet *et al.*, 2009). As discussed before, precipitation is known for washing out air pollution, it is known that high precipitation periods cause less PM concentrations in the atmosphere (Mircea, Stefan and Fuzzi, 2000; Zhang *et al.*, 2018). During the precipitation event, as well as straight after a precipitation event, the PM concentrations decrease (Ouyang *et al.*, 2015). After a precipitation event, large pollution loads can be measured in the rainwater droplets (Ouyang *et al.*, 2015). It has been found that precipitation has a larger impact on PM10 concentration than on PM2,5 concentrations. This is due to the fact that PM10 particles are larger and therefore wash away easier than PM2,5 particles (Zhang *et al.*, 2018).

1.6. Spatial distribution of particulate matter

The location of the PM measurements is known to have a significant effect on the measured concentrations (Hofman *et al.*, 2013; Jie *et al.*, 2016). Location characteristics and surrounding infrastructures impact the accumulation or wash out of the PM particles. Within an urban area, urban structures can also impact meteorological factors, and with this, the PM concentrations (Mayer, 1999; Zheng, Liu and Hsieh, 2013). Urban structures that are of high importance are: traffic proximity (Künzli *et al.*, 2000; Baldauf *et al.*, 2013), urban or rural area (Oke *et al.*, 2017), distance to park or green space (Selmi *et al.*, 2016), street canyon width and length (Gromke and Ruck, 2009; Zhang *et al.*, 2015; Oke *et al.*, 2017) and altitude (Oke *et al.*, 2017) as concentrations are highest nearest to the surface.

The PM concentrations are known to be different when measured at ground level by walking and cycling when compared to stationary measurement stations (de Hartog *et al.*, 2010; Masic, Pikula and Bibic, 2017). Mobile PM measurements are known to give a realistic overview of the actual exposure to PM concentrations at ground level (Deshmukh *et al.*, 2020). Due to the inhomogeneous nature of PM concentration within an area, mobile measurements give the most accurate overview of the real-time spatial distribution (Weijers *et al.*, 2004; Hagler, Thoma and Baldauf, 2010; Baldauf *et al.*, 2012; Masic, Pikula and Bibic, 2017; Deshmukh *et al.*, 2019). By using data collected with mobile measurements, it is more likely to collect realistic values that are more similar to real-life population exposure values (Deshmukh *et al.*, 2020). The mobile monitoring of PM has also proved to be a useful technique in order to analyse the spatial variability as well as the gradient concentration from specific sources (Deshmukh *et al.*, 2020).

As traffic is a large contributor to PM concentrations, it is only logical that the PM concentrations are known to increase in proximity to traffic on roads and highways (Künzli *et al.*, 2000; Baldauf *et al.*,

2012). As can be expected traffic intensity is linearly correlated to PM concentrations, higher traffic intensity on a road over all leads to higher PM concentrations (Baldauf *et al.*, 2012; Merbitz, Fritz and Schneider, 2012). Other aspects that are of importance to the PM concentrations on roads are the type of motor vehicles and the speed limits as well as the material of the road (Gulliver and Briggs, 2005; Baldauf *et al.*, 2012). On roads it is known that the traffic on the road cause the highest PM concentration values in the closest 200-300 meters next to the roads (Deshmukh *et al.*, 2020). Furthermore, the surrounding structure of the road is of importance to the PM concentration. Within urban canyons the PM emission from traffic will accumulate greatly reducing the air quality (Mayer, 1999). Whereas, research shows that roads in proximity to vegetation cause less harm to surrounding populations as the vegetation blocks the particulate deposition onto leaf and branch surfaces (Deshmukh *et al.*, 2019).

Vegetation around roads are not the only place where PM concentrations are known to be reduced. Green spaces and (urban) parks are generally known to reduce the PM concentrations (Chen *et al.*, 2016; Selmi *et al.*, 2016). Plants and trees are known to remove air pollutants, the main reason vegetation reduces air pollution is due to dry deposition on the plant surfaces (Nowak, Crane and Stevens, 2006). These particles are then washed off by the rain and thus are removed from the atmosphere (Vieira *et al.*, 2018). Another way that urban vegetation can remove PM is by primary uptake of pollutants through leaf stomata. Within the leaf, the air pollutant gases are diffused into intercellular spaces and can be absorbed by the leaf's water films in order to form acids or to react within the inner leaf (Nowak, Crane and Stevens, 2006). This, all adds to the overall reduction of the PM concentration, therefore it is overall assumed that PM concentrations are lower within parks and near urban vegetation (Selmi *et al.*, 2016).

1.7. The study site

Within this research, the study site will be Vienna, Austria. The city of Vienna is located on the river Danube situated in the border region between the Alps and the Pannonian Plain. The area of Vienna is 414 km2 (Environmental Protection, 2006) the population of Vienna in 2020 was 1,929,944 (Fendt, 2008). Even though air pollution in Vienna is considered to be good overall, the PM concentrations are still exceeded over an 24 hourly bases at times (Kurz *et al.*, 2014). Traffic is known to be the most crucial source of pollution within Vienna (Hauck *et al.*, 2004), other known sources are households, small businesses, railways, boats and lastly agricultural activities (Kurz *et al.*, 2014). Additionally in wintertime local heating is an additional source (Hauck *et al.*, 2004). Due to the limited amount of local powerplants and production facilities in the direct surroundings, industrial emissions are only considered to have a small effect on the overall pollutants in Vienna (Hauck *et al.*, 2004). According to the European Environmental Agency (EEA), the total air pollution emissions of Austria have been decreasing over the past years (EEA, 2019).

In order to understand the spatial distribution of the PM concentrations in Vienna, mobile measurements will be taken. The mobile measurements will be carried out in one of Vienna parks; Green Prater in the

second district. Vienna is a green city, and about 5% of the entire city consists of parks, amounting to 19 km^2, they are distributed through the city (Environmental Protection, 2006). Prater park is located in Vienna's 2nd district called Leopoldstadt. The area of Leopoldstadt is 19,3 km^2, and it has a population of 105,897 (Stadt Wien, 2020b). It has a low density of residential areas, meaning the share of total district area, in Leopoldstadt, is 14,5%, and it is known for being a rather green and natural part of Vienna (Fendt, 2008). The Prater park used to be the imperial hunting pavilion; it was donated to the city and became a public area (Stadt Wien, 2020c; Wien, 2020). In 1976 the highway A23 was constructed in the lower Prater, this was a south/ east highway that became an important part for the transport in Vienna. This highway is located on a bridge and has eight lanes; it is provided with additional noise barriers (Stadt Wien, 2020a). Currently, the Prater is known as a meadow, with poplar tree groups and dense undergrowth (Stadt Wien, 2020a). The combination of the green area and the large highway as well as smaller roads makes it an interesting location to look at the spatial distribution of PM.

1.8. Objectives and hypothesis

As discussed, this research will look at the effects of meteorological conditions on PM10 and PM2,5 concentrations. This research will also analyse the spatial distribution of PM concentrations at ground level. All the research will be done within the city of Vienna, Austria. As this research will consist of two parts, there are two main research questions that will be answered.

Which meteorological conditions have a significant effect on the PM10 and PM2,5 concentrations?

The measured meteorological conditions (wind direction, cyclonic and anticyclonic conditions at 925hPa and 500hPa and humidity) will have a significant impact on the PM10 and PM2,5 concentrations.

To what extent does the spatial distribution effect the PM10 and PM2,5 concentrations?

The spatial distribution and with this, the surrounding characteristics of a location have a significant effect on the PM10 and PM2,5 concentrations and will impact the measured concentrations significantly.

2. Materials and Methods

The study contains two major parts. The first part concerns the first research question: Which meteorological conditions have a significant effect on the PM10 and PM2,5 concentrations? The second part relates to the second research question: To what extent does the spatial distribution effect the PM10 and PM2,5 concentrations? These two research questions will need different data collection and statistical analysis processes to obtain results. A final connection between the two research questions will be analysed.

2.1. The impact of meteorological conditions on the PM concentrations

For the analysis of the meteorological conditions on the PM10 and PM2,5 concentrations, data will be used from the 1st of June 1999 until the 9th of June 2018. Different databases will be used for the data, and different analyses will be performed.

2.1.1. Databases used

Within this research, the PM concentration data were collected in Vienna by 12 different measurement stations that collect data for the EEA database as well as the more local Umweltbundesamt. All the PM concentrations here are shown in $\mu g \cdot m^{-3}$. The 12 measurement stations take data at different locations within Vienna: their locations are shown in Figure 1. Thirteen of these different stations take PM10 concentration measurements, and six take additional measurements of PM2,5 concentrations. For this study, the PM concentration data will be used as an average per day. Each location has an European Station code to which they are referred. These codes and further information on the stations and their background have been shown in Table 1.

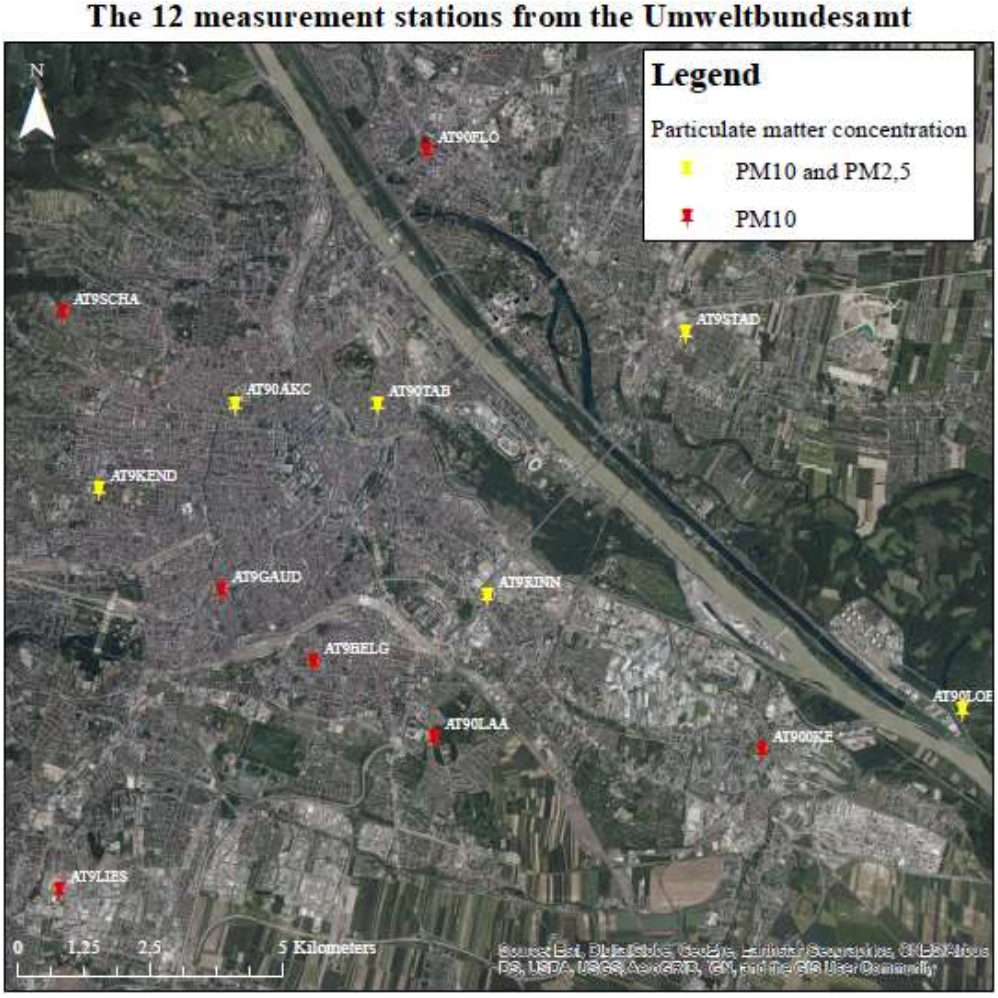

Figure 1: The locations of the measurement stations that measure the PM10 and PM2,5 concentrations in Vienna.

Table 1: Background information on all the measurement stations that provided the data for the PM2,5 and PM10 concentrations.

Station European code	Station name	Type of station	Station type of area	Street type	Station altitude	PM
AT90AKC	Wien AKH	Traffic	Urban	Wide street: L/H > 1.5	185	PM10 & PM2,5
AT9BELG	Wien Belgradplatz	Traffic	Urban	Wide street: L/H > 1.5	220	PM10
AT90FLO	Wien Floridsdorf Gerichtsgasse	Traffic	Urban	Wide street: L/H > 1.5	155	PM10
AT9GAUD	Wien Gaudenzdorf	Traffic	Urban	Wide street: L/H > 1.5	175	PM10
AT9KEND	Wien Kendlerstraße	Traffic	Urban	Canyon street: L/H < 1.5	230	PM10 & PM2,5
AT900KE	Wien Kaiserebersdorf	Traffic	Urban	Highway: average speed vehicles > 80 km/h	115	PM10
AT90LAA	Wien Laaer Berg	Background	Urban	Wide street: L/H > 1.5	250	PM10
AT9LIES	Wien Liesing	Traffic	Suburban	Wide street: L/H > 1.5	215	PM10

AT90LOB	Wien Lobau - Grundwasserwerk	Background	Suburban	Unknown	150	PM10 & PM2,5
AT9RINN	Wien Rinnböckstraße	Traffic	Urban	Highway:average speed vehicles > 80 km/h	160	PM10 & PM2,5
AT9SCHA	Wien Schafberg	Background	Suburban	Canyon street: L/H < 1.5	320	PM10
AT9STAD	Wien Stadlau	Background	Urban	Canyon street: L/H < 1.5	155	PM10 & PM2,5
AT90TAB	Wien Taborstrasse	Traffic	Urban	Canyon street: L/H < 1.5	160	PM10 & PM2,5

The data from the measurement stations will be analysed while looking at the meteorological conditions of Vienna. As discussed before in 1.2, the WLK weather classification method will be used by Dittmann et al. 1995 and Bissolli and Dittmann, 2003 (Dittmann *et al.*, 1995; Bissolli and Dittmann, 2003). The weather class is defined for all of Austria. Within this research the simplified version of the WLKC733 classification method will be used, this was developed in the framework of COST733 (Philipp *et al.*, 2010; Stanzel, Krennert and Nachtnebel, 2010). Within this classification method, one number is used, followed by three letters. The number is the true wind direction at 700hPa, the first and second letters denote cyclonic or anticyclonic conditions at 925hPa and 500hPa, and the last letter is the humidity level defined as dry or wet conditions that are identified according to a weighted area average value of the precipitable water, while compared to the long term daily average (Philipp *et al.*, 2010).

The Institut für Meteorologie und Klimatologie (Institute for Meteorology and Climatology) at Universität für Bodenkultur Wien (University of Natural Resources and Life Sciences, Vienna) (BOKU) weather measurements are taken each ten minutes. The weather station is located in the northwest of Vienna on top of the Schwackhöfer House in the Peter-Jordan-Strasse. From this database, data will be used to analyse the wind speed and precipitation. The wind speed will be a daily average of the 10-minute data in m/s and precipitation will be a daily average in mm.

2.1.2. The statistical analysis

For the analysis of the meteorological conditions, all weather classes will be analysed separately. This is done to test their individual significance on the PM concentrations. The effect of the weather classes will be analysed separately on the PM10 and PM2,5 concentrations. Within this research the PM10 concentrations that occur above the 50 $\mu g \cdot m^{-3}$ daily average threshold and the PM2,5 concentrations that occur above the 25$\mu g \cdot m^{-3}$ daily average will be analysed separately, in order to see if weather classes have a different effect on high PM concentrations. For the tests to check the significant differences, IBM SPSS statistics and Microsoft Excel will be used.

Initially, the PM10 and PM2,5 concentrations from the measurement stations will be analysed without including the meteorological conditions. This will be done to get a better understanding of the temporal and spatial distribution of the PM concentrations. The data will be analysed to see how the PM10 and PM2,5 concentrations are distributed throughout the year. As the measurements have been taken over

many years, an average will be taken to ensure that the values are representative for the PM concentrations in the different months. A plot will also be given to show how the PM10 and the PM2,5 are correlated within the dataset.

The PM10 and PM2,5 data needs to be tested for normal distribution. In order to do this, the Kolmogorov-Smirnoff test must be performed to see if the data is parametric or nonparametric distributed. The PM concentrations will be analysed in order to see if the measurements taken at different stations are significantly vary from each other. If the data is normally distributed, mixed linear models will be used to analyse if the stations have measured significant differences over time. If the data is not normally distributed the non-parametric Friedman's test will be used.

Analysis will be done comparing the different months or seasons to each other. When looking at the seasons, winter is January, February and March, spring is April, May and June, summer is July, August and September and autumn is October, November and December.

2.1.2.1. Wind direction

The WLKC733 weather classification identifies eight different wind directions. If the wind direction is not clearly one of the eight different directions or if the wind speed was not great enough, the wind direction gets the label undefined as can be seen in Figure 2. The main directions have a 30° sector, and the other directions have a 60° sector. If the wind direction could not be defined the wind direction gets a number 0 and is associated with the term ‘undefined’.

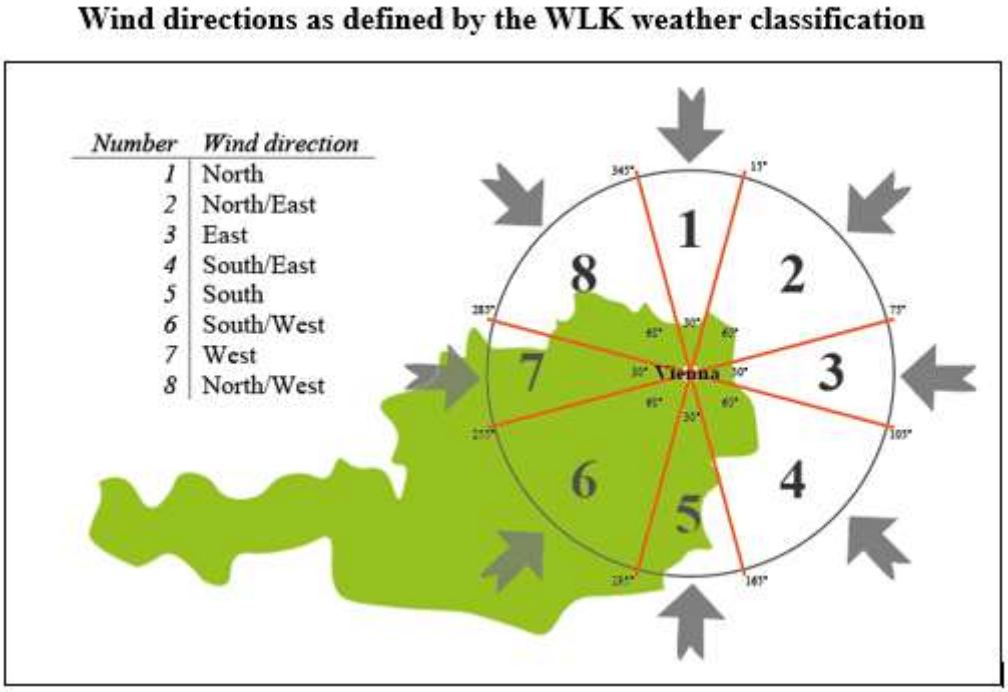

Figure 2: A visual map of Austria with the different wind directions and their associated numbers based on the WLKC733 wind classification wind directions.

Analysis will be done, in order to analyse if wind directions have a significant effect on the PM concentrations. In order to test which wind direction has caused the highest PM concentration, the unpaired T test will be used if the data is normally distributed and the Mann-Whitney U test will be used for not normally distributed data.

2.1.2.2. Wind speed

The wind speed has been given in m/s. Initially, the wind speed data will need to be analysed to test if the data is parametric or non-parametric. One-Sample Kolmogorov-Smirnov test will be performed on the collected wind speed data in order to determine this. In order to analyse the effect that the windspeed has on the PM concentrations, correlations will be made. If the PM concentrations and the wind speed are normally distributed the Pearson's rho correlation will be used to analyse the correlation, if the data is non-parametrically distributed the Spearman's rho correlation will be used.

2.1.2.3. Cyclonic or anticyclonic

The cyclonal and anticyclonic data was based on the weighted average value of the quasi-geostrophic vorticity and adding to this the higher weights were put on central grid points (Philipp *et al.*, 2010). The cyclonic and anticyclonic conditions will be analysed at 925hPa and 500hPa, in order to identify under which, condition the PM concentrations are highest. If the PM concentration data is normally distributed the unpaired T test will be used. If the data is not normally distributed the Mann-Witney U test will be used.

2.1.2.4. Humidity

As the outcome for the test of humid conditions can only be one of two options, dry or wet, the statistical analysis that will be performed, is similar to that performed with the cyclonic or anticyclonic conditions. The test will be performed to determine if PM concentrations are higher under dry or wet conditions. If the PM concentrations are normally distributed the unpaired T-test will be performed. If the PM concentrations are not normally distributed the Mann-Witney U test, will be performed.

2.1.2.5. Precipitation

The precipitation data will be given in mm, the tests used for the precipitation data will be similar to the tests used for the wind speed data. Initially, the precipitation data will be tested for normal distribution. The One-Sample Kolmogorov-Smirnov test will be performed on the collected wind speed data in order to test this. Then, in order to test if there is a relationship between precipitation and PM concentrations, correlations will be made. If the PM concentrations are parametrically distributed the Pearson's rho correlation will be used to analyse the correlation, if it is nonparametrically distributed the Spearman's rho correlation will be used.

2.2. The impact of the spatial distribution on the PM concentrations

For the analysis of the spatial distribution on the PM10 and PM2,5 concentrations, 6 different days in 2 periods will be analysed in order to see if location, time and meteorological conditions have an effect on the measured PM concentrations.

2.2.1. Data used

The data will be collected by doing mobile measurements. The mobile measurements will be done by cycling a pre-defend route through the Green Prater in the second district of Vienna. The exact route that will be analysed is shown in Figure 3. This route has different aspects that are known to influence the PM concentrations. This route crosses green spaces, large roads, smaller roads, urban areas and it also goes past a water body.

These mobile measurements will be taken in two different time periods. This is in order to see if it is possible to analyse the effect of seasonal changes with these measurements. The first set of measurements will be taken in March, as this is still a season when temperature inversion has an effect on the PM concentrations (Janhäll *et al.*, 2006). The second set of measurements will be taken in May in order to get measurements for warmer seasons without temperature inversion (Palarz and Celiński-Mysław, 2017). The measurements will take place on different days; the days will be picked randomly but based on certain criteria. They will need to be dry (no rain or snow), not too windy, and for the first measurement period, the temperature will need to be relatively cold. It will not be a problem if it will rain on the days prior to the sampling, however, as long as these rain events are of small duration (Hofman *et al.*, 2013). Furthermore, the measurements will be taken in mornings between 7.00 and 9.00 as this is when the temperature inversion is the strongest, and thus there are more pollutants in the morning (Palarz and Celiński-Mysław, 2017) and this time is during the Vienna rush hours. A minimum of 3 days sampling will be conducted for the quality purposes (Deshmukh *et al.*, 2020). The 3 different locations that are shown on the map will be analysed in more detail as they all show different properties that are important to analyse when looking at the PM concentrations. Details will be given in paragraph 2.2.2.1.

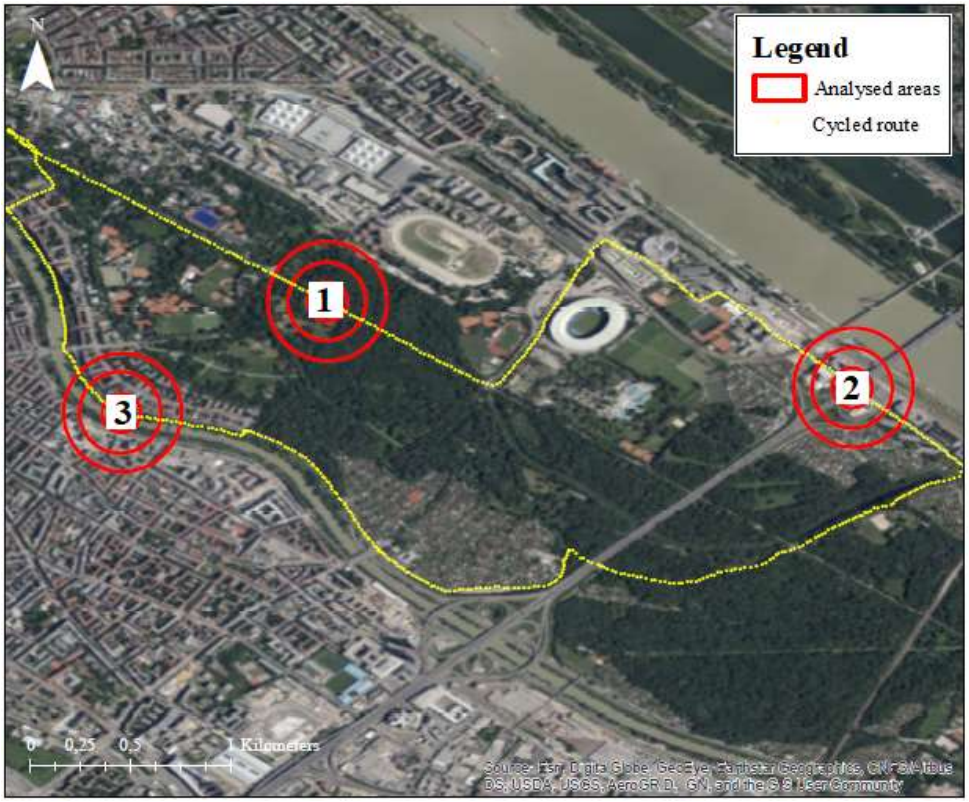

Figure 3: The predefined route that will be cycled when collecting the mobile measurement data with the PM sensor. The numbers 1,2 and 3 indicate locations where the data will be analysed in further detail.

The mobile data will be with the Nova PM sensor, model SDS011 in combination with a GPS, made at BOKU. The sensor takes a measurement of the particulate matter concentrations, it takes different measurements for PM10 and PM2,5 concentrations, as well as the time of these measurements and their coordinates. The Nova PM sensor works using a principle of laser scattering and can analyse the PM concentrations between 0,3 to 10 µg in the air. With the laser scattering principle, light is introduced when particles enter though a detecting area. The scattered light is transformed into electric signals. These signals are then amplified and processed. The signal waveform has a reaction with the particle diameter of the PM particle (Amaral *et al.*, 2015). The Nova PM sensor will be placed on a bicycle at the height of 95cm.

2.2.2. The statistical analysis

When looking at the data collected, different analyses will be performed. The analysis will be done in order to see if location, time, weather and seasons have an effect on the measured PM10 and PM2,5 concentrations. Different programs will be used to analyse the data, these programs are IBM SPSS statistics, ArcMap, and Microsoft Excel.

Initially, an overview will be given of the days on which the measurements could be taken. As the machine is new, background information will be provided of the distribution of the data. Secondly, the PM concentration data needs to be tested for normal distribution. In order to do this, the Kolmogorov-

Smirnoff test must be performed to see if the data is parametric or nonparametric distributed. The outcome of this test will determine the tests used to analyse the data.

2.2.2.1. Location

Within ArcMap all the collected PM10 and PM2,5 concentration data will be made visual. This will be done by displaying maps that show the point PM concentration data of all the rounds.

Secondly, three different locations have been identified these locations will be significantly different from each other in locational characteristics as can be seen in Figure 3. The locations will be an area of 600m, as literature has shown that the closest 200 – 300m next to a road has the highest effect on the PM concentrations (Deshmukh *et al.*, 2019). Even though not all locations will be on or crossing large roads, similar sizes of locations will be used in order to assure that the measured locations are the same size. These three different locations are, location number 1 an urban park, location number 2 the large highway (A23), and lastly location number 3, a smaller road. All locations are measured over a length of 600m. location nr 2 has the middle point in the middle of the highway A23 with 300m before and 300m after this middle point. The data collected within these locations will be compared to each other in order to test if there are truly significant differences between the different locations. If the measured data is normally distributed unpaired T-test will be performed. If the PM concentrations are not normally distributed the Mann-Witney U test will be performed. By doing this test, it will able to see within which location the PM concentrations are highest.

2.2.2.2. Time

The PM concentrations were measured in two rounds, the first one between 7.00 and 8.00 and the second round between 8.00 and 9.00 in the morning. In order to test at which measured time period (round) the PM concentrations are the highest the unpaired T test will be used if the data is normally distributed and the Mann-Whitney U test will be used for not normally distributed data.

2.2.2.3. Meteorological conditions

The impact of the weather classes will be analysed to test if they have a relation to the PM concentrations that have been measured on the different measurement days. This will be done by testing for significant differences between the measurement days, if the PM concentrations are normally distributed the unpaired T-test will be used and if the PM concentration data is not normally distributed the Mann-Whitney U test will be used. after this test to see which day has the highest PM concentration the data will be compared to the weather classes from the WLK weather classification method as well as the weather class data from BOKU. Lastly the difference between the two measurement periods will be tested. This will be done by using the unpaired T test if the PM data is normally distributed and using the Mann-Whitney U test if the PM data is not normally distributed.

3. Results

The meteorological conditions and their impact on the PM concentrations will first be analysed. This will be followed by the data collected with the mobile PM sensor and the analysis of the spatial distribution of the PM concentrations.

3.1. The impact of meteorological conditions on PM concentrations

In order to know what tests will be used to analyse the PM concentration data, the PM data needs to be tested for normal distribution. Appendix A, shows the output for the Kolmogorov-Smirnoff test. The results show that the PM10 and the PM2,5 concentrations are not normally distributed.

PM2,5 particles are also counted within the PM10 particles. Therefore, there is always a correlation between the two. As PM10 particles increase, it is likely that the PM2,5 particles also increase. Figure 4, shows the scatter plot of the measured PM10 concentrations compared to the PM2,5 concentrations. There is a strong correlation between the PM10 and the PM2,5 concentrations (Linear R^2= 0,860). The scatter pot has been colour coordinated by month that the measurement was made. The results show that most of the high outliers occur during the months January and February. It can be said that the PM10 and PM2,5 data collected within the measurement period has a high correlation.

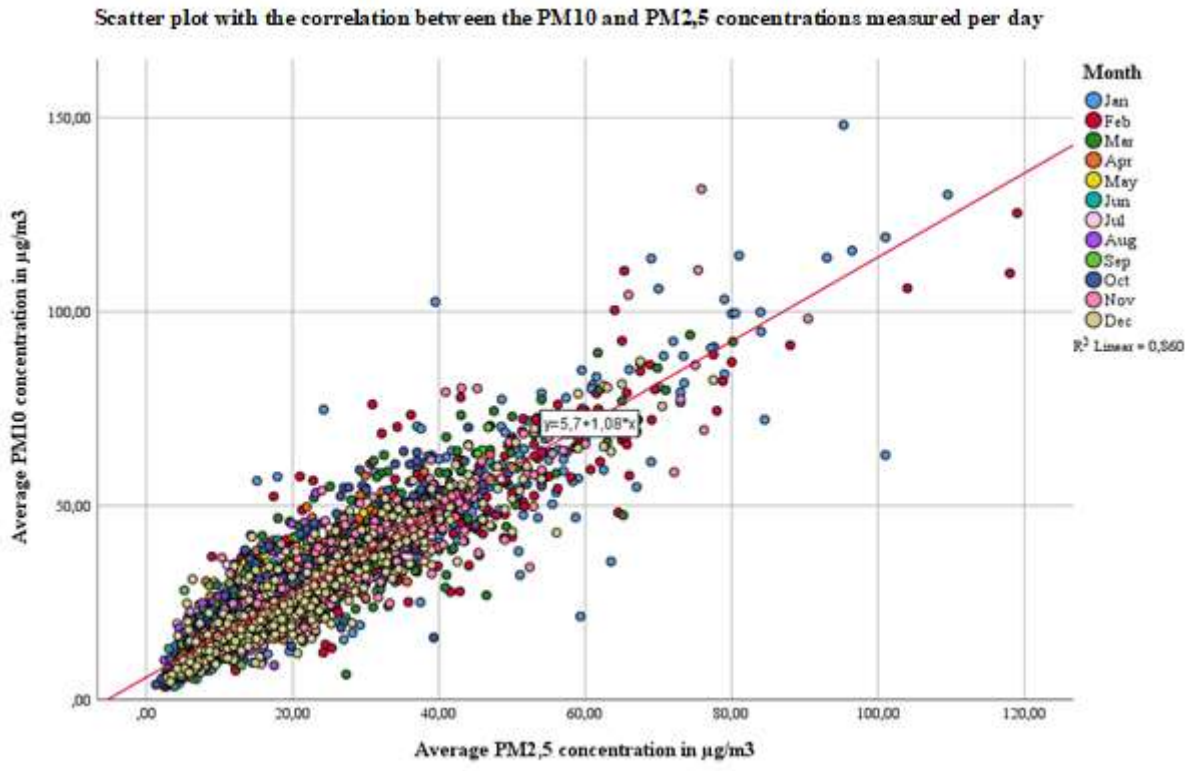

Figure 4: Scatter plot of average PM10 and PM2,5 concentrations of all the data, colour coordinated by months.

As the PM concentrations are known to fluctuate through time and space, all the average PM concentrations per month are shown for each station in Figure 5 and Figure 6. Figure 5 displays the

average PM10 concentrations for all the stations are shown for each month. Figure 6 displays the same for the PM2,5 concentrations. Both figures show a clear difference between the PM concentrations within the summer months and winter months. The PM concentrations are in both cases lower in summer and higher in winter, as is expected.

The figures also indicate that there are slight differences between the different measurement stations. Figure 5 shows that the highest PM10 concentrations in winter can be found at station AT90TAB and AT9RINN. The lowest concentrations throughout the year can be found at stations AT90LOB and AT9SCHA. When looking at the exact locations of these measurement stations in Figure 1, it can be seen that the stations that indicate measuring higher PM10 concentrations are located more in the centre of Vienna, whereas the stations measuring the lower PM10 concentrations are located more outside of the city centre. Furthermore, the station AT9RINN is located near a highway with average traffic and the AT90TAB station is located within an urban area near traffic, thus higher PM concentrations are expected. This contrasts with the AT90LOB station and AT9SCHA station that are located in background suburban areas, that would expect to measure lower PM concentrations.

When looking at Figure 6, the measurement station with the highest value is harder to identify the highest PM2,5 concentrations in the figure. As the concentrations are all similar in value and follow a similar pattern. The lowest PM2,5 concentration throughout the year belongs to the measurement station AT90LOB, this is a station on the outer sides of the city, like with the PM10 concentrations, the measurement station on the outside of the city has measured lower PM concentrations. The figures also show that the PM10 concentrations are higher than the PM2,5 concentrations.

An interesting appearance in the figures is the dip in the PM concentrations in winter as well as a slight peak in summer. In Figure 6, there are two clear peaks in February and November, as expected the PM2,5 concentrations are higher in winter months than summer months. There seems to be a small dip in the concentrations in January and December. A potential reason for this phenomenon is due to Christmas vacation, when less people complete a daily commute to work. This dip in concentrations is also visible in December in Figure 5. However, it is not as clearly visible. The peak in summer months is less obvious, Figure 5 shows there is a small increase in PM10 concentration in July. In Figure 6 there is no real peak in the summer month PM2,5 concentration. As this peak only occurs with the PM10 concentrations, it could potentially be due to an increase of dust particles within the warmer summer months.

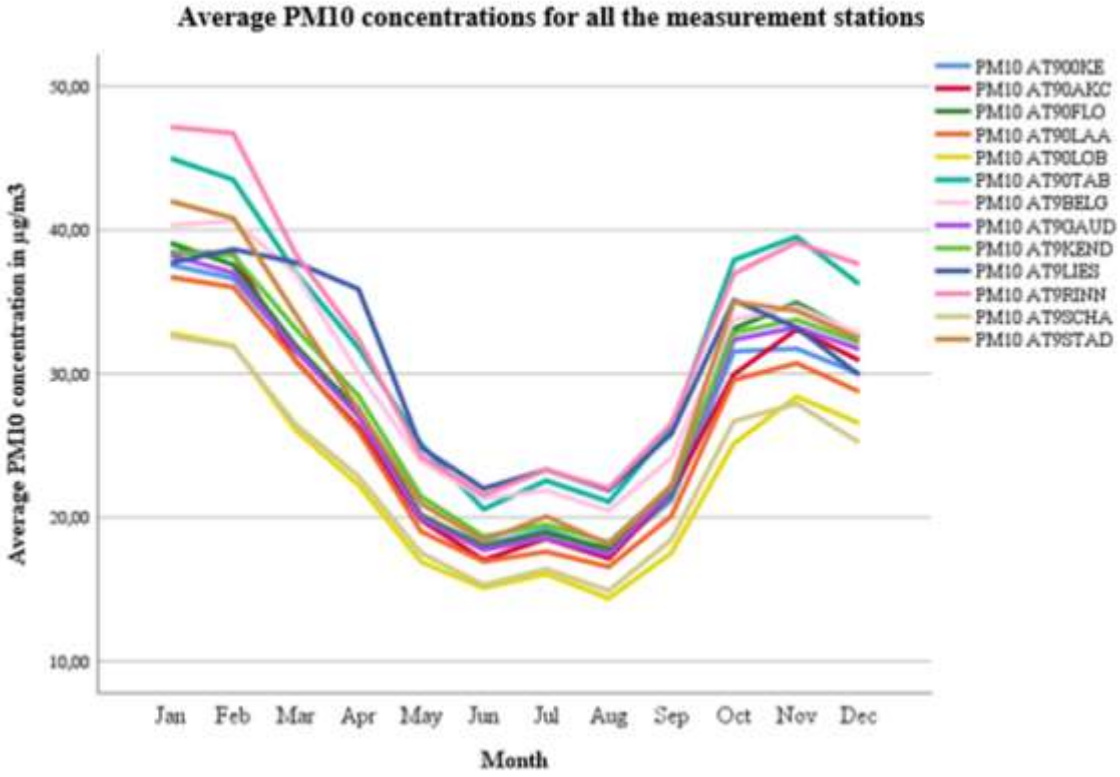

Figure 5: Average PM10 concentrations for all the measurement stations divided by month. Concentrations are analysed in $\mu g \cdot m^{-3}$.

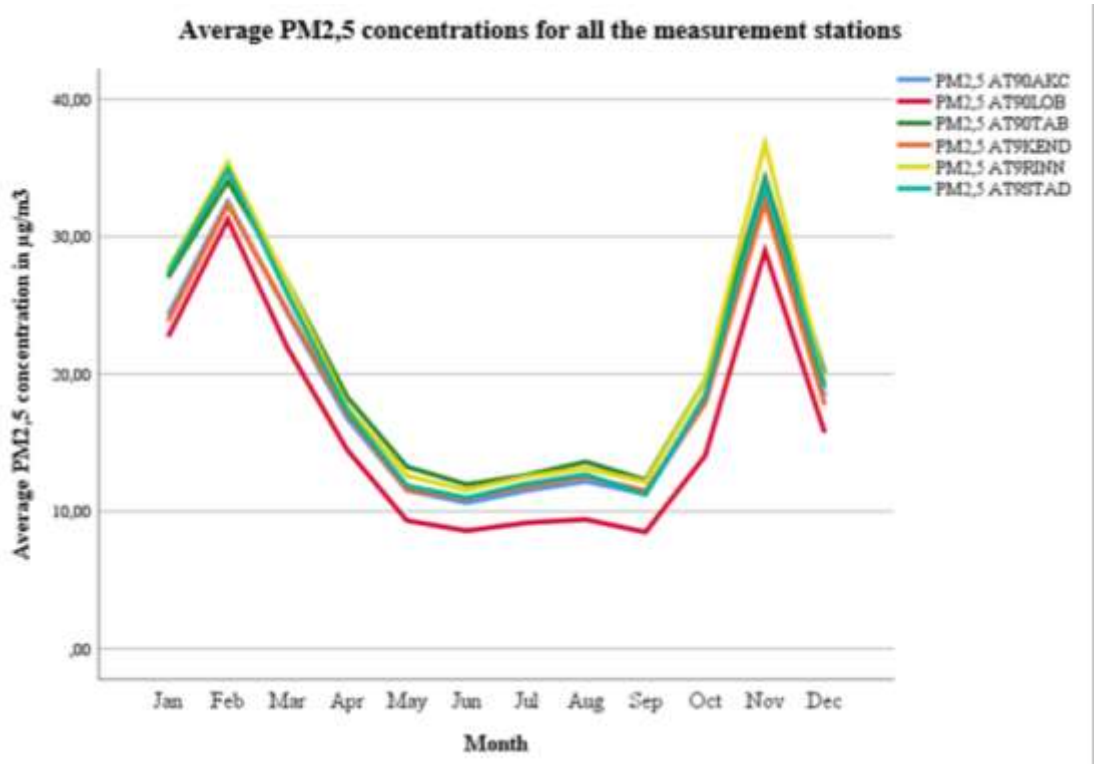

Figure 6: Average PM2,5 concentrations for all the measurement stations divided by month. Concentrations are analysed in $\mu g \cdot m^{-3}$.

Figure 5 and Figure 6 show that there are differences between the different measurement stations and the PM concentration that they have measured through the measurement period. The figures, however, do not show if this difference is significant. As the Kolmogorov-Smirnoff test in Appendix A shows, distribution of the PM concentrations at the measurement stations is nonparametric. Thus, the non-parametric Friedman test will be performed in order to test if there is a significant difference between the PM concentrations that have been measured at the different measurement stations. The output for the non-parametric Friedman test, is shown in Table 2 and **Error! Reference source not found.**.

Table 2: The measurement stations, the type of station and their Station European codes with their average PM concentrations over the entire measurement period.

Station European code	*Station name*	*Type of station*	*Average PM10 concentration in $\mu g \cdot m^{-3}$*
PM10 AT900KE	Wien Kaiserebersdorf	Traffic	26,18
PM10 AT90AKC	Wien AKH	Traffic	24,73
PM10 AT90FLO	Wien Floridsdorf Gerichtsgasse	Traffic	27,29
PM10 AT90LAA	Wien Laaer Berg	Background	25,52
PM10 AT90LOB	Wien Lobau - Grundwasserwerk	Background	22,26
PM10 AT90TAB	Wien Taborstrasse	Traffic	28,52
PM10 AT9BELG	Wien Belgradplatz	Traffic	27,32
PM10 AT9GAUD	Wien Gaudenzdorf	Traffic	25,83
PM10 AT9KEND	Wien Kendlerstraße	Traffic	25,90
PM10 AT9LIES	Wien Liesing	Traffic	28,57
PM10 AT9RINN	Wien Rinnböckstraße	Traffic	33,43
PM10 AT9SCHA	Wien Schafberg	Background	22,96
PM10 AT9STAD	Wien Stadlau	Background	28,67
PM10 Average			26,48

Station European code	*Station name*	*Type of station*	*Average PM2,5 concentration in $\mu g \cdot m^{-3}$*
PM2,5 AT90AKC	Wien AKH	Traffic	18,38
PM2,5 AT90LOB	Wien Lobau - Grundwasserwerk	Background	13,96
PM2,5 AT90TAB	Wien Taborstrasse	Traffic	18,80
PM2,5 AT9KEND	Wien Kendlerstraße	Traffic	18,12
PM2,5 AT9RINN	Wien Rinnböckstraße	Traffic	19,89
PM2,5 AT9STAD	Wien Stadlau	Background	19,04
PM2,5 Average			18,62

Table 3: The test statistic output for the non-parametric Friedman test

	PM10	*PM2,5*
N	2581	1011
Chi-Square	9683,878	2258,803
df	13	6
Asymp. Sig.	0,000[a]	0,000[a]

[a] Significant difference is displayed (p<0,05)

Table 2 shows the average values that were measured at the PM10 and PM2,5 measurement stations. When looking at these values, it is visible that the average PM10 concentrations are higher than the PM2,5 concentrations. Within the PM10 concentrations, the highest concentration can be found at measurement station AT9RINN, as can be expected this is a measurement station within the city centre of Vienna. The lowest PM10 concentrations can be found for the measurement stations AT90LOB and AT9SCHA, as mentioned before, these are stations outskirts of the city centre and contain little traffic. For the PM2,5 concentrations, the highest values were measured at the measurement stations AT9RINN and AT9STAD; both are located in the city centre and are heavily surrounded by traffic. The lowest average concentration was measured at measurement station AT90LOB, this is a measurement station far outside of the city centre and surrounded by little traffic.

Table 3gives the statistical output of the non-parametric Friedman's test. The output of the test shows that there is a significant difference among the PM10 concentrations as well as the PM2,5 concentrations (p<0,05). This means that the PM concentrations that were measured at all the PM10 stations were statistically different from each other, the same goes for the measurements taken at the PM2,5 stations.

When looking at the health effects of PM concentrations, the higher the concentrations are, the more damaging they are to human health. The higher concentrations are therefore also more interesting to analyse, in order to see under which conditions, they occur most. Thus, the high PM concentrations and the weather patterns that cause them are an interesting phenomenon to look at separately. When looking at the data from the 1st of June 1999 until the 9th of June 2018 the high PM10 concentrations, above 50 $\mu g \cdot m^{-3}$ and the high PM2,5 concentrations above 25 $\mu g \cdot m^{-3}$ it can be seen that over the entire period on some of the days concentrations that were measured, were above the recommended threshold concentrations. Among the PM10 concentrations 10,21% of the daily observations that were made at all the measurement stations were above the 50 $\mu g \cdot m^{-3}$ threshold. And among the PM2,5 concentrations 21,61% of the daily observations that were made on all the measurement stations were above the 25 $\mu g \cdot m^{-3}$ threshold. Table 4 shows the amount of days that were observed each year, as well as the annual average and the amount of days that one or more of the measurement stations measured concentrations above the threshold.

Table 4: The average PM10 and PM2,5 concentrations of all the measurement stations in Vienna and the annual amount of observations, the annual average concentration and the amount of observation above the recommended threshold.

	PM10 concentrations			PM2,5 concentrations		
Year	Amount of days observed	Annual average	Days with an average concentration above 50 $\mu g \cdot m^{-3}$	Amount of days observed	Annual average	Days with an average concentration above 25 $\mu g \cdot m^{-3}$
1999[e]	204	28,79	16	208	20,90	63[d]
2000	149	32,72	22	140	23,71	41[d]
2001[f]	0		0	0		0
2002	365	27,23	43[c]	0		0
2003	365	34,91	65[c]	0		0
2004	366	25,89	25	0		0
2005	365	30,05	54[c]	350	23,89	135[d]
2006	365	31,55	48[c]	365	23,24	117[d]
2007	365	24,95	25	365	19,18	81[d]
2008	366	23,91	21	366	18,45	77[d]
2009	365	26,02	24	365	19,54	85[d]
2010	365	30,07	50[c]	365	21,57	103[d]
2011	365	30,41	47[c]	365	20,54	99[d]
2012	366	24,65	26	366	16,88	68[d]
2013	365	25,77	26	365	17,89	84[d]
2014	365	22,96	17	365	15,57	67[d]
2015[f]	0		0	0		0
2016	366	19,01	9	366	13,24	39
2017	365	19,85	20	365	13,69	44
2018[g]	160	24,04	7	160	16,84	29

[a] Annual concentrations exceed the 40 $\mu g \cdot m^{-3}$ threshold.

[b] Daily threshold of 50 $\mu g \cdot m^{-3}$ is exceeded more than 25 days per calendar year.

[c] Annual concentrations exceed the 25 $\mu g \cdot m^{-3}$ threshold.

[d] Daily threshold of 25 $\mu g \cdot m^{-3}$ is exceeded more than 25 days per calendar year.

[e] In 1999 measurements were not taken throughout the year, in 1999 the observations start on the 1st of June and were made until the end of the year.

[f] No data available for these years.

[g] In 2008 measurements were not taken throughout the year, there are observations available from the start of the year until the 9th of June.

When looking at the results in Table 4 for the PM10 and the PM2,5 the annual average always follows the Austrian environmental agency guidelines, however in most years the WHO guidelines are exceeded. When looking at the amount of exceedance days each year, there are far more days for the PM2,5 concentrations than for the PM10 concentrations were the threshold concentrations are exceeded.

3.1.1. The impact of wind direction on PM concentration

As mentioned before, the WLKC733 weather classification identifies eight different wind directions. Through the measurement period, these wind directions have not occurred in the same frequency. The distribution of the wind directions over the measurement period is shown in Figure 7.

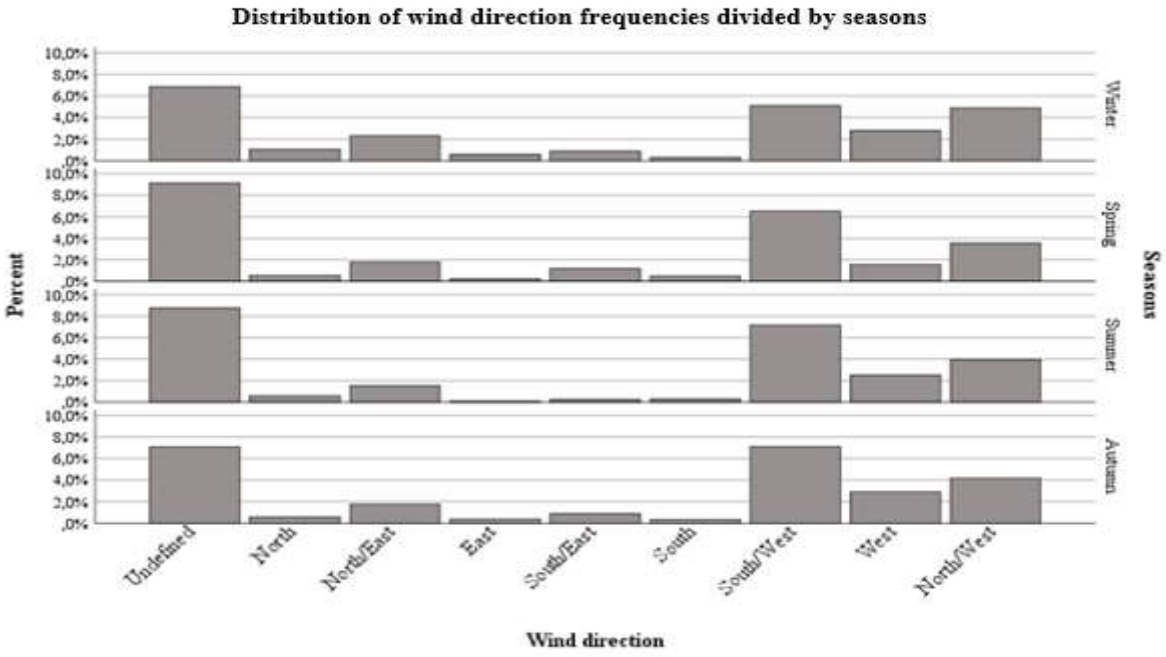

Figure 7: Different wind directions and the number of times they appear in percentages over the measurement period as a function of the season the measurements are taken in.

Figure 7 shows that there is little seasonal variability within the measured wind directions. As there is little seasonal variability between wind direction and seasons, the seasons will be clustered in further analysis of the wind direction and the effect on PM concentration. The figure shows that almost a third of the time, the wind direction was undefined, thus meaning that the wind speed was not fast enough to consider the wind direction to have an effect or the wind direction was not clear enough to define it to a specific wind direction. The most frequent wind directions that occur in Vienna are south/west, west, and north/west winds. The winds from the east, south, south/east and north occur the least frequent. There seems to be a clear differentiation in the frequency of the wind directions as shown in the figure. The figure does not say anything about the impact of these wind directions on the PM concentrations.

As the Kolmogorov-Smirnoff test in Appendix A shows, distribution of the PM concentrations at the measurement stations is nonparametric. Thus, the Mann-Whitney U test will be used to test the significant differences between the PM10 and PM2,5 at the different wind directions. Background information of the Mann-Whitney U test will be shown in Appendix B.

3.1.1.1. Wind directions and PM10 concentrations

Figure 8 shows the distribution of the PM10 concentrations at different wind directions.

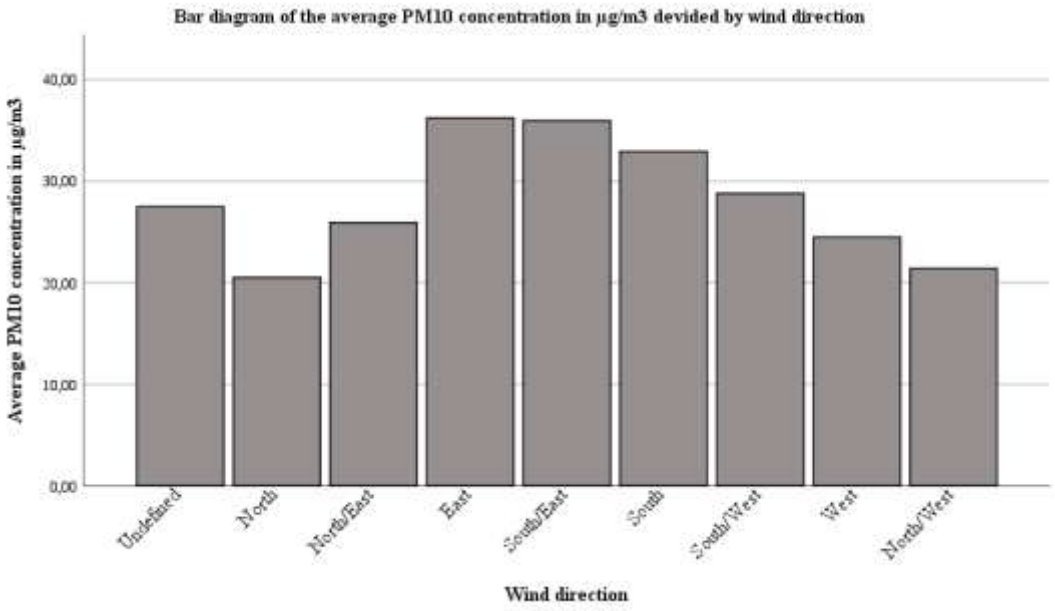

Figure 8: Average PM10 concentrations in µg·m^{-3} as a function of the wind directions.

Figure 8 shows that there are differences within the average PM10 concentrations that have been measured with different wind directions. The highest average PM10 concentrations are measured under south-eastern winds, followed by eastern and southern winds. The figure also shows that the lowest PM10 concentrations are measured during northern winds and north-western winds. The summarized output for the Mann-Witney U test is shown in the table below, the full output for the Mann-Whitney U test is shown in Appendix B, Appendix Table 2.

Table 5: Summarized output for Mann-Whitney U test of the average PM10 values in µg·m^{-3} and the different wind directions.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	0,000[a]								
North/East	0,013[a]	0,000[a]							
East	0,000[a]	0,000[a]	0,000[a]						
South/East	0,000[a]	0,000[a]	0,000[a]	0,665					
South	0,000[a]	0,000[a]	0,000[a]	0,933	0,605				
South/West	0,000[a]	0,000[a]	0,000[a]	0,009[a]	0,000[a]	0,000[a]			
West	0,000[a]	0,001[a]	0,188	0,000[a]	0,000[a]	0,000[a]	0,000[a]		
North/West	0,000[a]	0,828	0,000[a]	0,000[a]	0,000[a]	0,000[a]	0,000[a]	0,000[a]	

[a] Significant difference are displayed at 0,05 level.

Table 5, shows that although most wind directions show that mean equal ranks cannot be assumed, between some wind directions there is no significant difference. In Figure 8 the highest average PM10 concentrations can be found with southern winds.

Table 5 shows that there is no significant difference between southern, eastern, and south/eastern winds (p>0,05). Thus, it can be said that the wind directions that cause the highest PM10 concentrations are southern, eastern, and south/eastern winds. South-western winds followed by the undefined, western and north/eastern winds cause the next highest PM10 concentrations. Lastly, the PM10 concentrations from northern and north/western winds are not significantly different from each other and cause the lowest PM10 concentrations (p>0,05). The same analysis will be done, by only looking at the PM10 concentrations that have been measured above the threshold concentration.

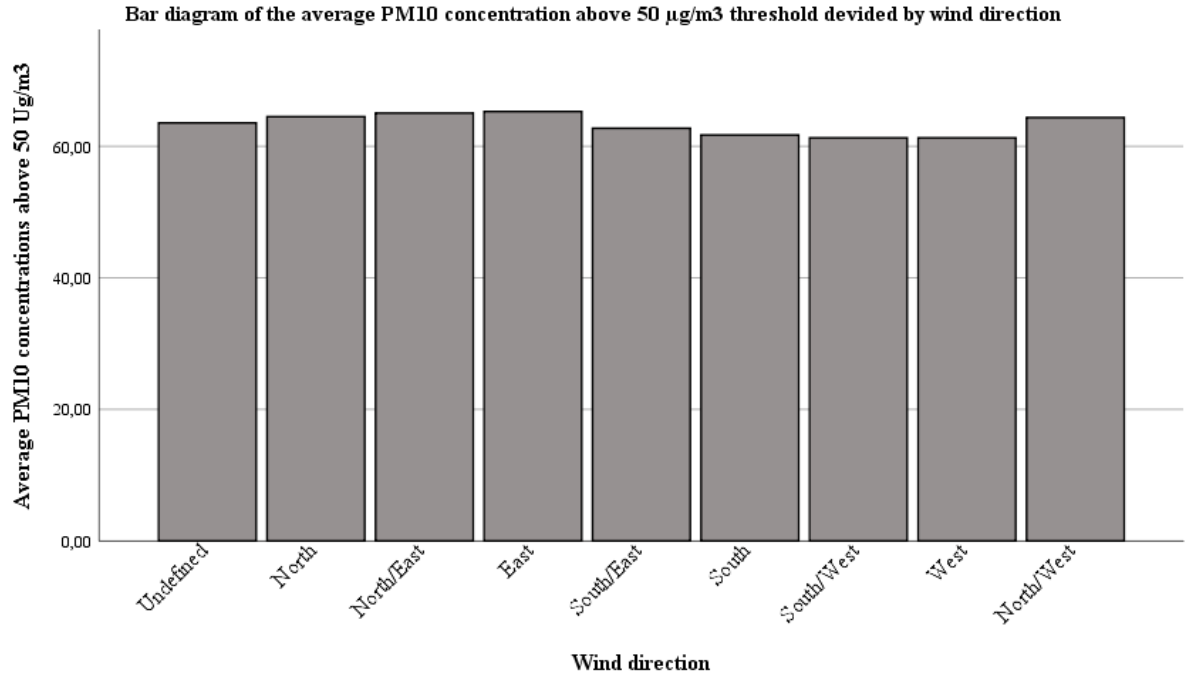

Figure 9: Average PM10 concentrations in µg·m^{-3} above the 50 µg·m^{-3}threshold as a function of the wind directions.

Figure 9 shows that the PM10 concentrations that are measured above the 50 µg·m^{-3} threshold. The figure shows that even though the wind directions do not occur within the same frequencies within each season, the variation in occurring frequencies each seasons is similar with the highest number of high PM10 concentrations occurring during undefined and south/western wind conditions and the lowest frequencies of high PM10 concentrations occurring during north, east and southern winds. Thus, it can be assumed that there are no big differences between the occurrence of wind directions and seasons.

Table 6: Summarized Output for Mann-Whitney U test of the average PM10 values in that were measured above the 50 µg·m^{-3} threshold and the different wind directions.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	0,507								
North/East	0,712	0,642							
East	0,557	0,889	0,736						
South/East	0,512	0,426	0,353	0,379					
South	0,245	0,187	0,212	0,147	0,424				
South/West	0,175	0,297	0,229	0,279	0,930	0,447			
West	0,633	0,361	0,497	0,409	0,744	0,407	0,642		
North/west	0,664	0,630	0,957	0,721	0,351	0,194	0,168	0,417	

[a] Significant difference are displayed at 0,05 level.

Table 6 show that there is no significant difference between the average PM10 concentrations above 50 µg·m^{-3} and the wind directions (p>0,05). This means that PM10 concentrations above the 50 µg·m^{-3} threshold is considered to be the same for each of the analysed wind directions. Thus, meaning that wind direction is not of significant importance to high PM10 concentrations

In summary, when looking at all the PM10 concentrations eastern, south/eastern and southern winds lead to the highest PM10 concentrations measured at the measurement stations in Vienna. And north-western and northern winds lead to lowest PM10 concentrations measured in Vienna. When analysing only the highest PM10 concentrations as measured above the threshold, there is no significant difference in the wind direction and the height of the PM10 concentrations.

3.1.1.2. Wind directions and PM2,5 concentrations

The same process will be repeated while looking at the PM2,5 concentrations.

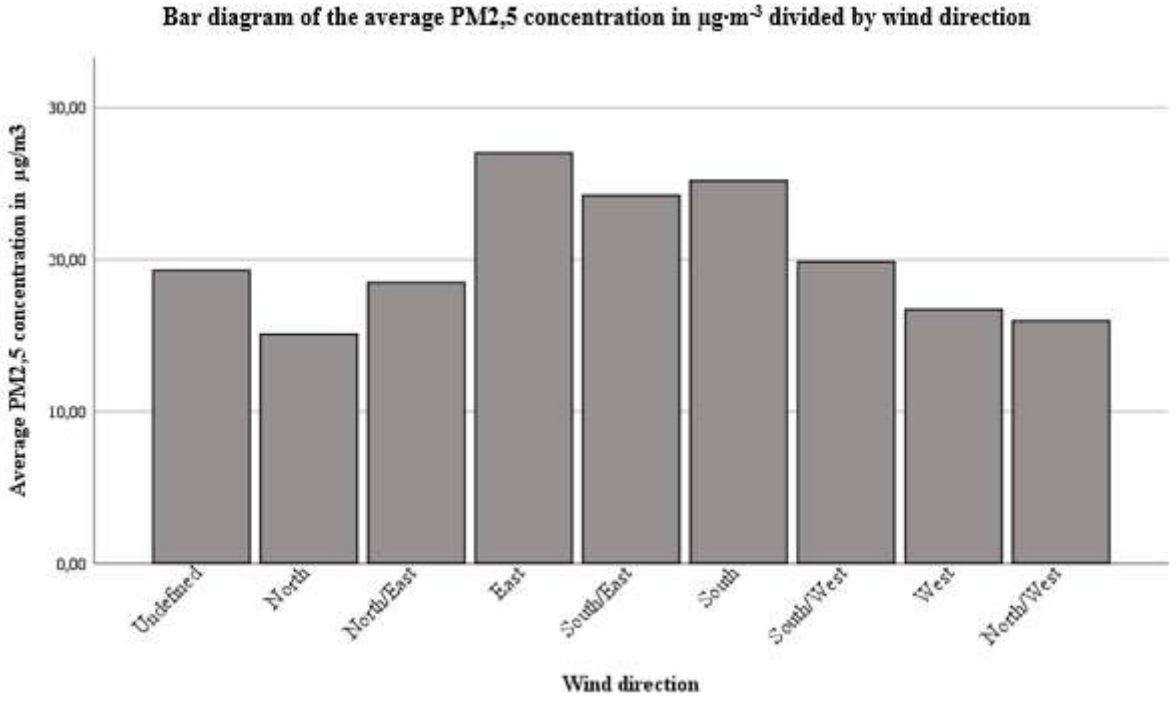

Figure 10: Average PM2,5 concentrations in µg·m^{-3} as a function of the wind directions.

Figure 10 shows that there are some differences in the distribution of the PM2,5 concentrations. The highest PM2,5 concentration is found with north/western winds, this is however an outlier. The higher median concentration can be found with an eastern wind. There is a large amount of variation between the measured PM2,5 concentrations. The boxplot does not show the significant differences between the stations. The significant differences between the different wind directions have been analysed with the Mann-Whitney U test in Table 7.

Table 7: Summarized output for Mann-Whitney U test of the average PM2,5 values in µg·m^{-3} and the different wind directions.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	0,000								
North/East	0,089[a]	0,003							
East	0,000	0,000	0,000						
South/East	0,000	0,000	0,000	0,478[a]					
South	0,000	0,000	0,000	0,809[a]	0,000				
South/West	0,017	0,000	0,002	0,001	0,000	0,000			
West	0,000	0,068[a]	0,097[a]	0,000	0,000	0,000	0,000		
North/west	0,000	0,526[a]	0,000	0,000	0,000	0,000	0,000	0,040	

[a] Asymptotic significances are displayed

Table 7 shows that between many wind directions a significant difference has been found between the PM2,5 concentrations ($p<0,05$). The full output for the Mann-Whitney u test is given in appendix B, Appendix Table 4. In the results it is clear that there is no significant difference between eastern winds, south/eastern winds as well as southern winds. The highest PM2,5 concentrations are found under eastern, southern and south/eastern wind directions followed by south/western and undefined winds. followed by western, north/western and north/eastern winds. Like in the PM10 observations, northern winds lead to the lowest PM2,5 concentrations. There is no significant difference between the northern winds and the western and north/western winds. The difference between the western winds and the north/western winds are significantly different and the north/eastern winds are not significantly different from the undefined winds.

Looking at all the PM2,5 concentrations combined could potentially lead to different results than looking at only the high concentrations. Due to the importance of the high PM2,5 concentrations and the large variation that has been observed within the measured PM2,5 concentrations, the next part will analyse the PM2,5 concentrations that have been measured above the 25$\mu g \cdot m^{-3}$ concentration threshold. Within Figure 11 the frequency of the wind directions on the days with high PM2,5 concentrations above the threshold concentrations are shown.

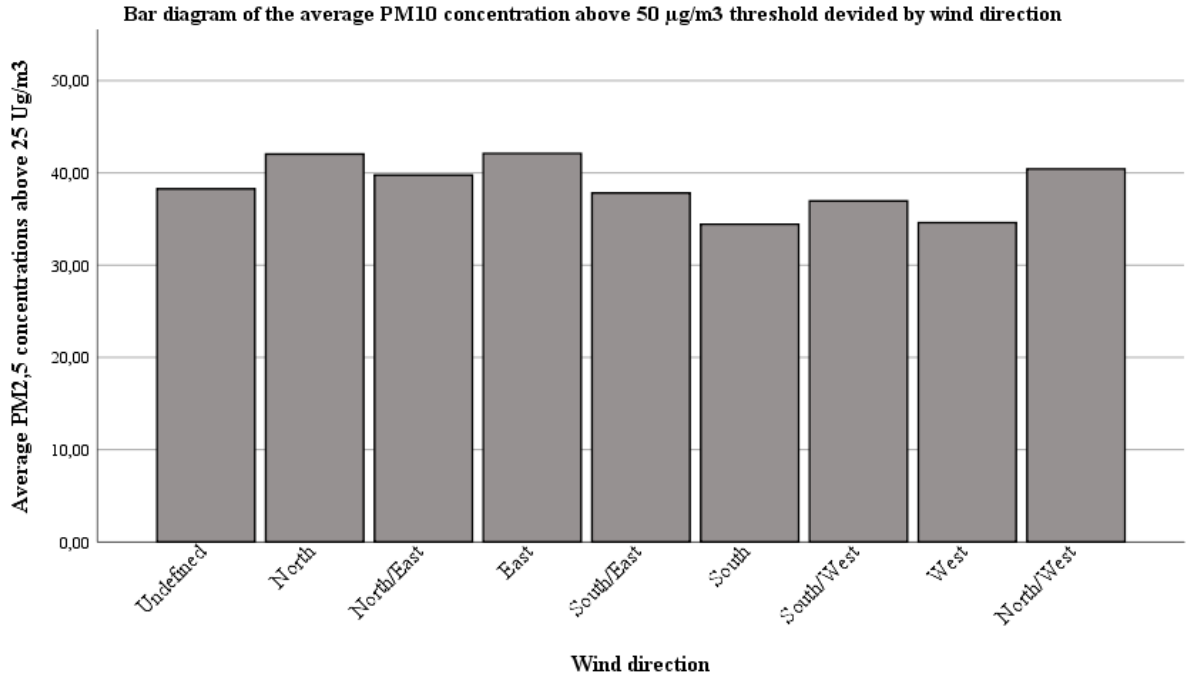

Figure 11: Average PM2,5 concentrations in $\mu g \cdot m^{-3}$ above the 25 $\mu g \cdot m^{-3}$threshold as a function of the wind directions.

In Figure 11 the frequency of the wind PM2,5 concentrations above the threshold concentration is shown. The figure shows that there is little variation between the average PM2,5 concentrations measured at the different wind directions. It seems like the highest average PM2,5 concentrations above the threshold are measured with eastern winds and the lowest with southern or western winds. In order

to test if these differences are significant Table 8 shows the summarized output of the Mann-Whitney U test of the average PM2,5 concentrations measured above the threshold and the wind directions.

Table 8: Summarized Output for Mann-Whitney U test of the average PM2,5 values in that were measured above the 25 $\mu g \cdot m^{-3}$ threshold and the different wind directions.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	0,059 [a]								
North/East	0,827 [a]	0,139 [a]							
East	0,106 [a]	0,749 [a]	0,241 [a]						
South/East	0,669 [a]	0,065 [a]	0,941 [a]	0,200 [a]					
South	0,393 [a]	0,019	0,376 [a]	0,061 [a]	0,306 [a]				
South/West	0,628 [a]	0,035	0,627 [a]	0,061 [a]	0,498 [a]	0,486 [a]			
West	0,046	0,004	0,121 [a]	0,009	0,068 [a]	0,820 [a]	0,096 [a]		
North/west	0,161 [a]	0,223 [a]	0,480 [a]	0,423 [a]	0,439 [a]	0,113 [a]	0,073 [a]	0,005	

[a] Asymptotic significances are displayed

Table 8 shows that there are hardly significant differences between the average PM2,5 concentrations measured above the threshold and the wind direction. Significant differences can be found between undefined winds and western winds, as well as between northern winds and southern, south/western and western winds and between eastern winds and western wind. Lastly western winds show a significant difference to north western winds ($p>0,05$). The complete output of the Mann-Whitney U test in Appendix B, Appendix table 6, shows that in all cases the northern wind direction have the highest average PM2,5 concentration. Between the undefined wind and western wind, the undefined wind has the highest PM2,5 concentration and with the western and north/western winds the highest PM2,5 concentrations can be found with north/western winds.

In summary, when looking at all the PM2,5 concentrations, eastern, south/eastern and southern winds lead to highest PM2,5 concentrations measured at the measurement stations in Vienna. And north/western, northern and western winds lead to lowest PM2,5 concentrations measured in Vienna. When looking at the PM2,5 concentrations that have been measured above the $25 \mu g \cdot m^{-3}$ threshold, the wind direction does always have a significant effect on the PM2,5 concentrations. However, northern winds lead to significantly higher concentrations than south, south/western and western winds. Undefined winds lead to significantly higher concentrations than western winds and north/western winds lead to significantly higher concentrations than western winds.

The results show that wind direction has a significant effect on the PM10 and the PM2,5 concentrations. However, wind direction seems to have a smaller effect on the PM10 and the PM2,5 concentrations when the concentrations are higher.

3.1.2. The impact of wind speed on PM concentration

Even though wind speed and wind directions are analysed separately here, wind direction is an important aspect when analysing the effect of windspeed on the PM concentrations. Figure 12 shows a distribution of the average daily wind speed compared to the daily wind direction. As mentioned before, it is important to note here that when no wind direction could be detected or when the wind speed was not considered to be strong enough, the wind direction was defined as undefined.

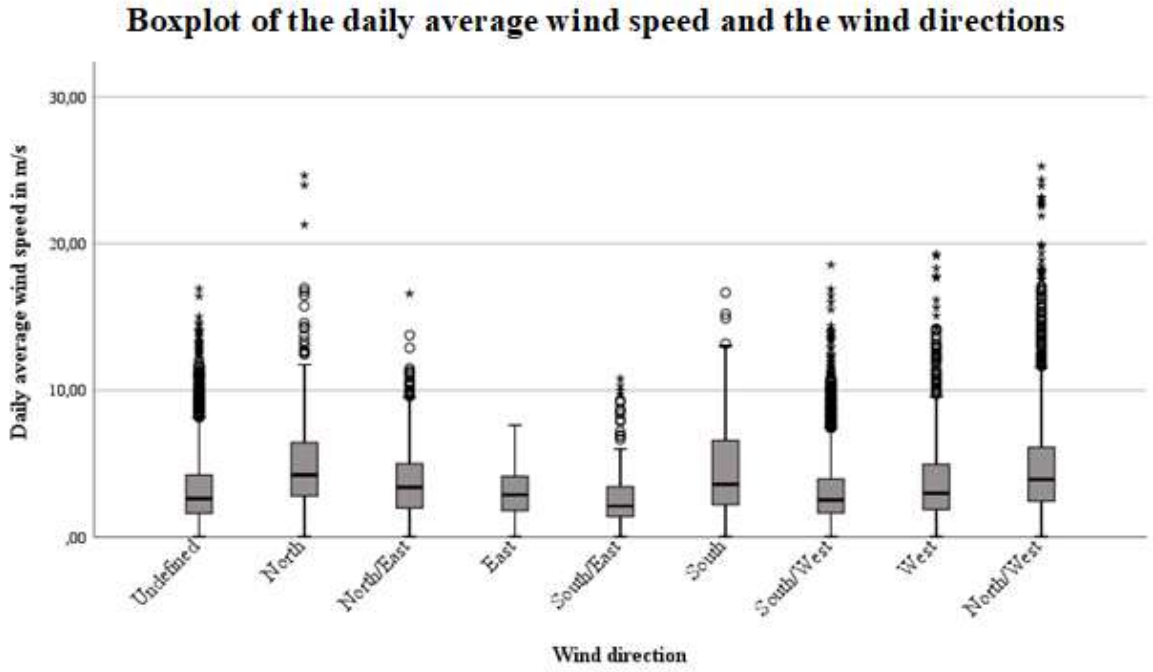

Figure 12: Boxplot of the average daily wind speed compared to the wind direction.

Figure 12 shows that there is a lot of variation in between the daily average wind speed and the different wind directions. The figure shows that there is some variation between the different wind directions, especially when looking at the maximum values that have been measured. It would be expected that the lowest wind speeds would be found within the undefined wind speeds, however, this is not specifically the case. From the figure it is clear that eastern winds have no outlying values. The highest average wind speeds can be found with northern, south/eastern, and north/western winds. The lowest wind speeds can be found with the undefined wind speeds as well as the east, south/eastern and south/western winds. The figure shows that there are some relations between wind speed and wind direction.

In order to know what test to use for the correlation between PM concentrations and wind speed, the wind speed needs to be tested to see if the data is normally distributed. In Appendix C the Kolmogorov-Smirnoff test has been performed. The data shows that the measured wind speed is nonparametric. As Appendix A shows that the PM concentrations are also nonparametric the Spearman's rho correlation will be used.

3.1.2.1. Wind speed and PM10 concentrations

Figure 13, shows the scatter plot with the correlation between the average PM10 concentrations and the average daily wind speed in m/s.

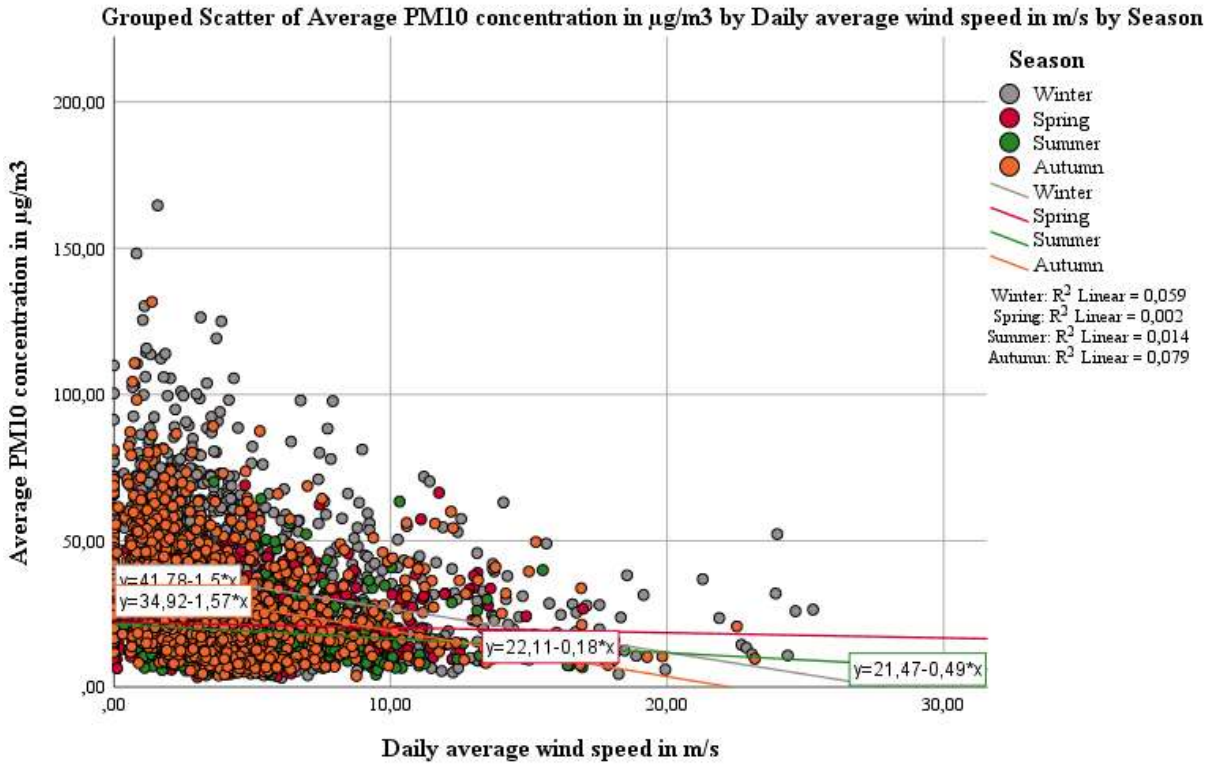

Figure 13: Scatter plot of the average PM10 concentrations in µg·m^{-3} and the daily average wind speed in m/s divided by season.

Figure 13, depicts the correlation between the average daily PM10 concentrations from all the measurement stations and the average daily wind speed. The figure shows there is a very low or even no correlation between the two, in all of the four seasons (winter linear R^2 = 0,059, spring linear R^2 = 0,002, summer linear R^2 = 0,014, autumn linear R^2 = 0,079). When looking at the scatter plot, the values seem clustered and there is no indication that there is a correlation either. The Spearman's rho correlation will give a more precise answer in order to determine the correlation between the two.

Table 9: Output from the Spearman's rho correlation on the average PM10 concentrations in µg·m^{-3} and the daily average windspeed in m/s.

			Average PM10 concentration in µg·m^{-3}	Daily average wind speed in m/s
Spearman's rho	Average PM10 concentration in µg·m^{-3}	Correlation Coefficient	1,000	-0,246 [a]
		Sig. (2-tailed)	-	0,000 [a]
		N	5992	5992
	Daily average wind speed in m/s	Correlation Coefficient	-0,246 [a]	1,000
		Sig. (2-tailed)	0,000 [a]	-
		N	5992	6949

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 9 shows the output of the Spearman's rho correlation, the correlation coefficient indicates a weak correlation but significant correlation between the average PM10 concentration and the daily average wind speed (R_S= -0,246, n =5992, p<0,05). As there is a weak correlation this explains why the linear R^2 within Figure 13 indicates such a low value. The same will be analysed for the PM10 concentrations that have been measured above the threshold concentrations.

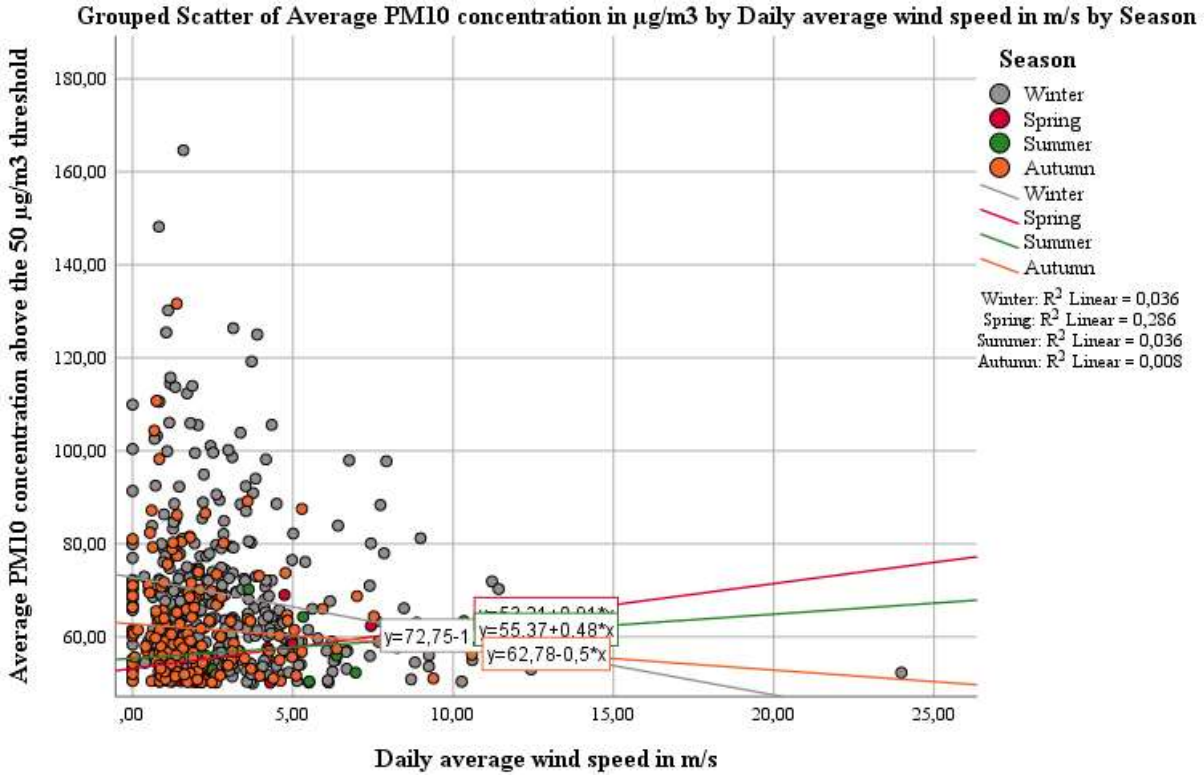

Figure 14: Scatter plot of the average PM10 concentrations above the 50 µg·m-3 threshold concentration in µg·m^{-3} and the daily average wind speed in m/s.

Figure 14 shows the scatter plot of the PM10 concentrations that were measured above the threshold concentrations and the wind speeds associated with them. There are far less measured values than in Figure 13. Within this scatter plot the measured concentrations are also clustered within the bottom left corner. The figure also shows that there is a very weak or even no correlation between the two (winter linear R^2= 0,0036, summer linear R^2= 0,036, autumn linear R^2= 0,008). Except when looking at the correlation within spring, here it shows that there is only a weak correlation between the two (spring linear R^2= 0,286). Thus, the highest correlation between the two can be found in the spring months. The Spearman's rho correlation will be executed in order to further analyse the potential correlation as overall the correlation is considered to be weak and therefore, the different seasons will not be analysed separately when testing the data for correlation.

Table 10: Output from the Spearman's rho correlation on the average PM10 concentrations above the 50 µg·m^{-3} threshold concentration and the daily average wind speed in m/s

			Average PM10 concentrations above µg·m^{-3}	Daily average wind speed in m/s
Spearman's rho	Average PM10 concentrations above µg·m^{-3}	Correlation Coefficient	1,000	0,089 [a]
		Sig. (2-tailed)	-	0,002[a]
		N	1175	1175
	Daily average wind speed in m/s	Correlation Coefficient	0,089 [a]	1,000
		Sig. (2-tailed)	0,002 [a]	-
		N	1175	1175

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 10 shows the output for the Spearman's rho correlations (R_S= -0,089, n=1175, p<0,05). The correlations coefficient is very small and thus it can be expected that there is no correlation between the PM10 concentrations above the threshold values and the daily average wind speed.

The results in this chapter indicate that the daily average wind speed has a weak negative correlation with the measured PM10 concentrations. Meaning that with increased windspeed, the PM10 concentrations slightly decrease. When looking at the PM10 concentrations that are measured above the predefined threshold concentration, the wind speed does not have a correlation with the measured PM10 concentrations. Within these results it shows that the impact that windspeed has on the measured PM10 concentrations is minimal.

3.1.2.2. Wind speed and PM2,5 concentrations

The same analysis concerning correlations between PM concentrations and wind speed as in chapter 3.1.2.1 will be performed within this chapter. However, this chapter will look at the impact of wind speed on the PM2,5 concentrations.

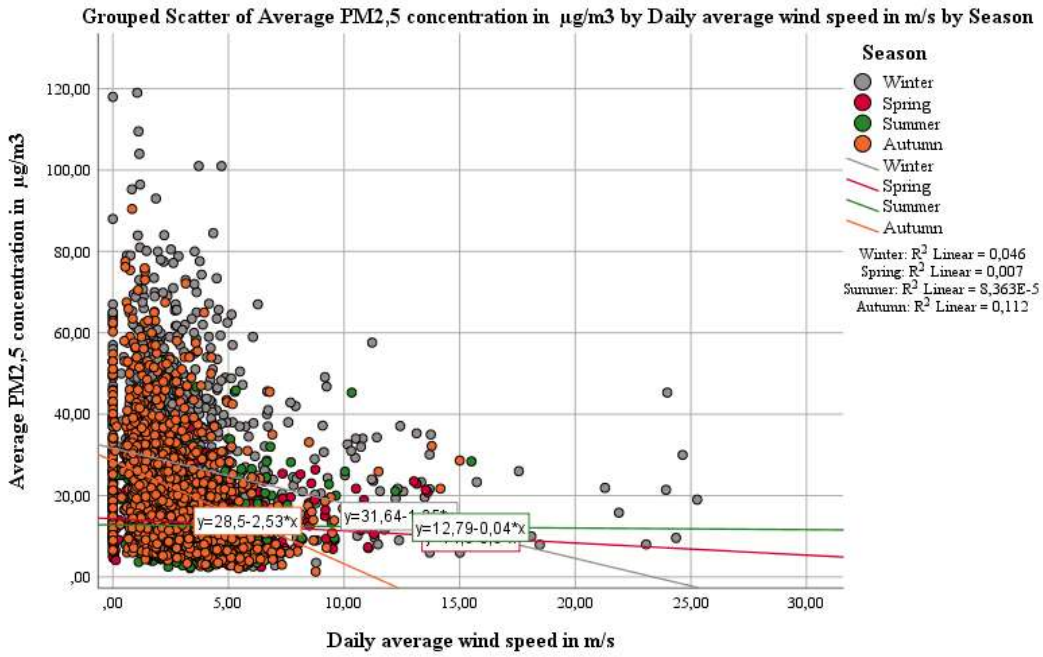

Figure 15: Scatter plot of the average PM2,5 concentrations in µg·m^{-3} and the daily average wind speed in m/s. Data defined by season that the measurement was taken in.

Figure 15 shows the scatter plot of the average PM2,5 concentrations and the daily average wind speed. The plot shows that like with the PM10 concentrations, most of the values are clustered within the lower left corner. The figure shows that in each season, there is very low, or even no correlation between the two (winter linear R^2 = 0,046, spring linear R^2 =0,007, summer linear R^2 = 8,363E^{-5} and autumn linear R^2 = 0,112). However, due to the large amount of values that are measured the Spearman's rho can give a more precise overview. As all the seasons show little to no correlation in the plot, the seasons will not be separated within the Spearman's rho correlation.

Table 11: Output from the Spearman's rho correlation on the average PM2,5 concentrations in µg·m^{-3} and the daily average windspeed in m/s.

			Average PM2,5 concentration in µg·m^{-3}	Daily average wind speed in m/s
Spearman's rho	Average PM2,5 concentration in µg·m^{-3}	Correlation Coefficient	1,000	-0,241[a]
		Sig. (2-tailed)		0,000 [a]
		N	4876	4876
	Daily average wind speed in m/s	Correlation Coefficient	-0,241[a]	1,000
		Sig. (2-tailed)	0,000 [a]	-
		N	4876	4876

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 11 shows the output for Spearman's rho correlation for the average PM2,5 concentrations and the daily average wind speed. The correlation coefficient indicates a weak negative correlation but significant correlation between the two (R_S =-0,241, n= 4876, p<0,005). This means that there is a weak negative correlation between the two, and just like with the PM10 concentrations this correlation has been found to be significant. Thus, as wind speed increases, PM2,5 concentrations decrease.

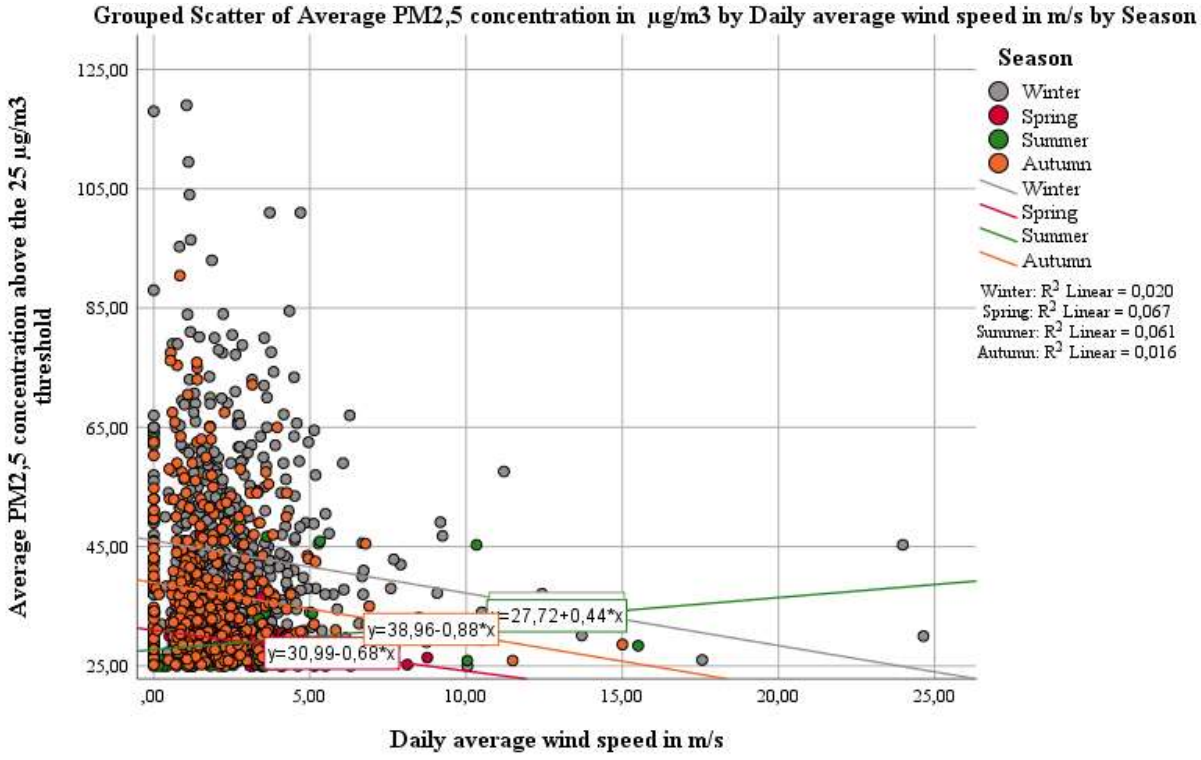

Figure 16: Scatter plot of the average PM2,5 concentrations above the 25 µg·m-3 threshold concentration in µg·m^{-3} and the daily average wind speed in m/s divided by season.

Figure 16 shows the scatterplot of the average PM2,5 concentrations that have been measured above the threshold. The figure shows that there is only a very weak or even no correlation between the two (winter linear R^2 = 0,020, spring linear R^2 = 0,067, summer linear R^2 = 0,061, autumn linear R^2 = 0,016). When looking at the figure it can be seen that a large amount of the observations are clustered within the lower left corner. However, due to the large variation in the observations the Spearman's rho correlation will be performed in order to test this correlation.

Table 12: Output from the Spearman's rho correlation on the average PM2,5 concentrations above the 25 µg·m^{-3} threshold concentration and the daily average wind speed in m/s.

			Average PM2,5 concentrations above 25 µg·m^{-3}	Daily average wind speed in m/s
Spearman's rho	Average PM2,5 concentrations above 25 µg·m^{-3}	Correlation Coefficient	1,000	0,070 [a]
		Sig. (2-tailed)	-	0,013 [a]
		N	1307	1254
	Daily average wind speed in m/s	Correlation Coefficient	0,070 [a]	1,000
		Sig. (2-tailed)	0,013 [a]	-
		N	1254	1254

[a] The correlation is significant at the 0,05 level (2-tailed).

Table 12 shows the output for the Spearman's rho correlation of the PM2,5 concentrations above the 25µg·m^{-3} threshold and the daily average wind speed. The outcome of the correlation indicates that there is no correlation between the two (R_S = -0,070, n =1254, p< 0,05). This result is significant. This is similar to the results found with the PM10 concentration above the threshold concentrations.

The results indicate that there is a weak negative correlation with the measured PM2,5 concentrations and the daily average wind speed. When wind speed increases, there is a small increase in PM2,5 concentrations. When looking at the PM2,5 concentrations that are measured above the threshold concentration, the wind speed also seems to have only a weak correlation with the PM2,5 concentrations. Thus, within these results, the impact that the wind speed has on the measured PM2,5 concentrations is minimal.

3.1.3. The impact of cyclonic or anticyclonic conditions on PM concentration

The cyclonic and anticyclonic conditions have been measured at 925hPa and 500hPa.

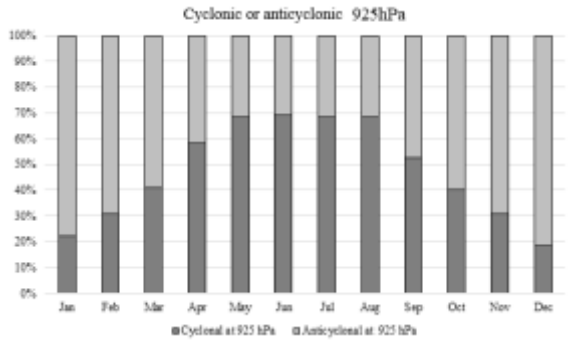

Figure 17: Cyclonic and anticyclonic conditions at 925hPa throughout the different months of the years when measurements were taken as a percentage of the represented data.

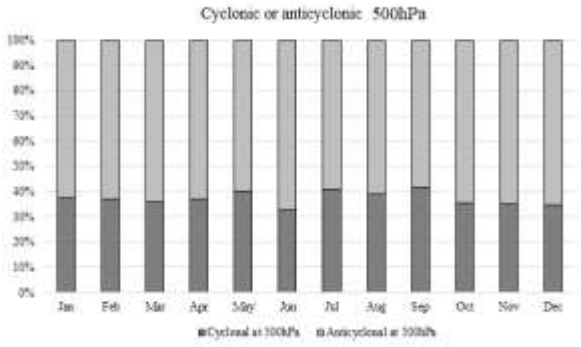

Figure 18: Cyclonic and anticyclonic conditions at 500hPa throughout the different months of the years when measurements were taken as a percentage of the represented data.

Figure 17 shows the distribution of the cyclonic and anticyclonic conditions in percentages divided over months. The figure shows that there is a trend in the distribution of the cyclonic and anticyclonic conditions. The cyclonic conditions occur more frequently within the summer months when temperatures are warmer. The anticyclonic conditions are more frequent within the winter months, January, February, November, and December when the temperatures are lower. Within Figure 18, the cyclonic and anticyclonic conditions are shown at 500hPa. Here there seems to be no clear trend within the different seasons. It can be seen in this figure that the cyclonic conditions are less frequent through the year than the anticyclonic conditions.

The following analysis that will be done is to see if there is a significant difference between the PM concentrations during the occurrence of cyclonic and anticyclonic conditions, in order to see if any of the conditions leads to significantly higher PM concentrations. The PM10 and PM2,5 concentrations are non-parametrically distributed as is shown in appendix A, thus, the Mann-Witney-U test will be used to test if there is a significant difference between the PM concentrations at the different measurement stations under the different cyclonal conditions these results will be shown in appendix D.

3.1.3.1. Cyclonic or anticyclonic conditions and PM10 concentrations at 925hPa

The cyclonic and anticyclonic conditions have been measured during the same measurement period as the PM concentrations. Within this paragraph the PM10 concentrations are analysed at 925hPa

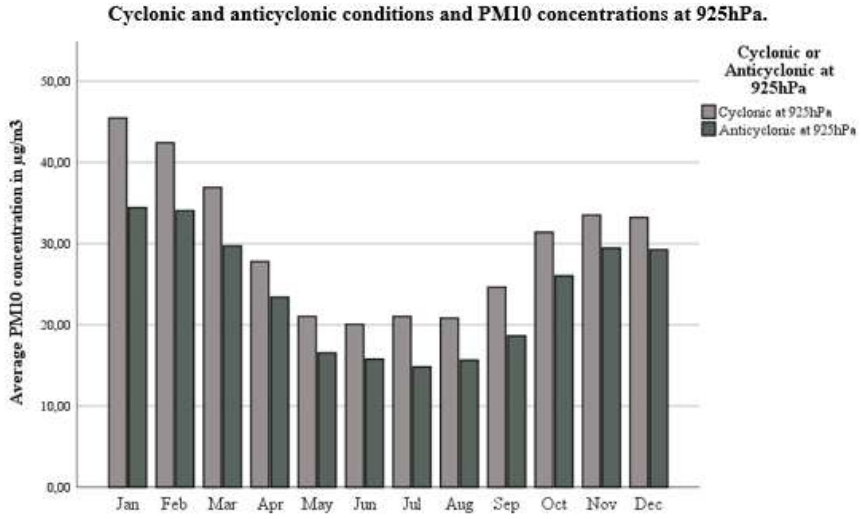

Figure 19: Bar diagram comparing PM10 concentrations for each month compared to each other depending on the cyclonic or anticyclonic conditions at 925hPa.

Figure 19 shows a bar diagram of the PM10 concentrations and the cyclonic and anticyclonic conditions over the different months. The figure shows that in each month the average PM10 concentration is higher under the cyclonal conditions. The figure does not show if this result is significant, in Appendix table 9, the output for the Mann-Whitney U test has been shown in order to test if this difference is significant. The results show that there is a significant difference between the cyclonic and anticyclonic conditions ($p<0,05$). The results also show that, as can also be seen in Figure 19, the cyclonic conditions cause higher PM10 concentrations.

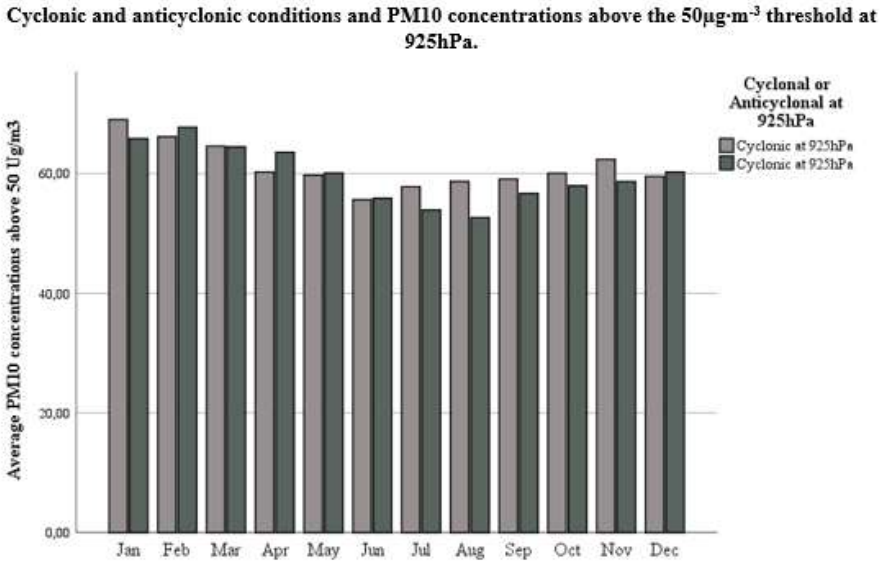

Figure 20: Bar diagram comparing PM10 concentrations above the 50µg·m^{-3} threshold for each month compared to each other depending on the cyclonic or anticyclonic conditions at 925hPa.

Figure 20 shows the PM10 concentrations above the 50µg·m^{-3} threshold and the cyclonic and anticyclonic conditions at 925hPa. The figure shows that there is less of a distinction between the PM10

concentrations and the months than found in Figure 19. The figure shows that in some months the PM10 concentration are higher with cyclonic conditions and in some months the concentrations are higher with anticyclonic conditions. The full output for the Mann-Whitney U test can be found in Appendix table 9, here it shows that there is no significant difference between the PM10 concentrations measured above the threshold and the cyclonic or anticyclonic conditions (p>0,05).

Thus, when it comes to PM10 concentrations and cyclonic or anticyclonic conditions at 925hPa, cyclonic conditions cause significantly higher PM10 concentrations when looking at all the PM10 concentrations, however when looking at only the higher PM10 concentrations there seems to be no significant difference between the two.

3.1.3.2. Cyclonic or anticyclonic conditions and PM10 concentrations at 500hPa

The same analysis will be performed looking at the PM10 concentrations and the cyclonic and anticyclonic conditions at 500hPa.

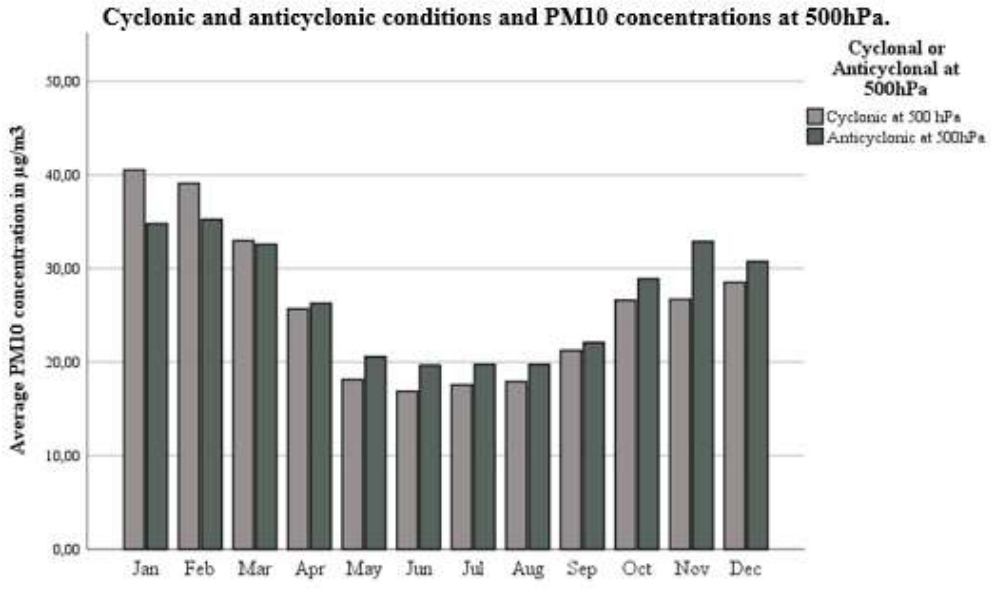

Figure 21: Bar diagram comparing PM10 concentrations for each month compared to each other depending on the cyclonic or anticyclonic conditions at 500hPa.

Figure 21 shows the average PM10 concentrations under cyclonic or anticyclonic conditions through the different months. As has been observed before, the PM10 concentrations are lower in the summer months and higher in the winter months. In some months cyclonic conditions seem to lead to higher average PM10 concentrations and in some months the anticyclonic conditions lead to higher PM10 concentrations. When looking at the output of the Mann-Whitney U test in Appendix table 9, here it shows that there is a significant difference between the PM10 concentrations under cyclonic and anticyclonic conditions (p<0,05). In this case the PM10 concentrations are significantly higher under anticyclonic conditions than cyclonic conditions. This is opposite to the findings found in chapter 3.1.3.1. when looking at the PM10 concentrations at 925hPa.

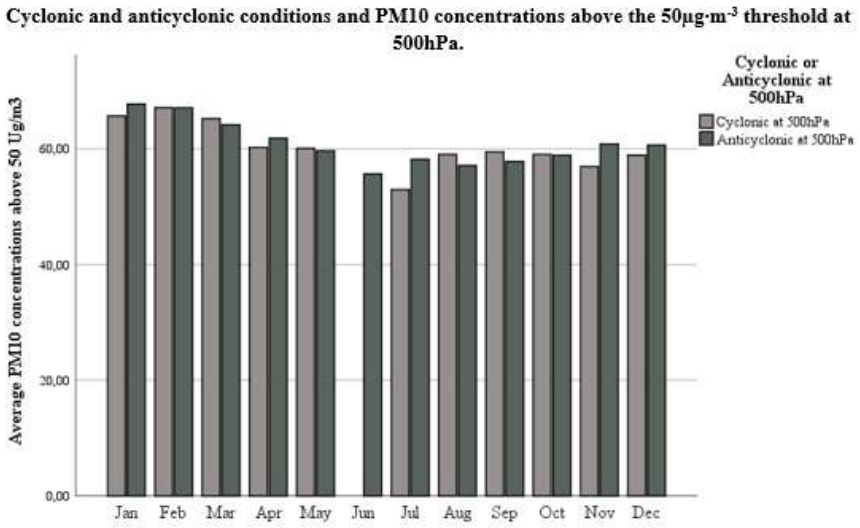

Figure 22: Bar diagram comparing PM10 concentrations above the 50µg·m-3threshold for each month compared to each other depending on the cyclonic or anticyclonic conditions at 500hPa.

Figure 22 shows the results for the PM10 concentrations above the threshold and the cyclonic or anticyclonic conditions at 500hPa. In the figure it can be observed that there were no PM10 concentrations above the threshold under cyclonic conditions in the month June. Some months the PM10 concentrations are higher under cyclonic conditions and some months the PM10 concentration can be found to be higher under anticyclonic conditions. In Appendix table 9 the full output of the Mann-Whitney U test shows that there is no significant difference between the PM10 concentrations under the different conditions.

Concluding, when looking at all the PM10 concentration values that have been observed, anticyclonic conditions cause significantly higher PM10 concentrations at 500hPa. When only looking at the high PM10 concentrations there is no significant difference under the different conditions.

3.1.3.3. Cyclonic or anticyclonic conditions and PM2,5 concentrations at 925hPa

The same process will be repeated looking at the PM2,5 concentrations.

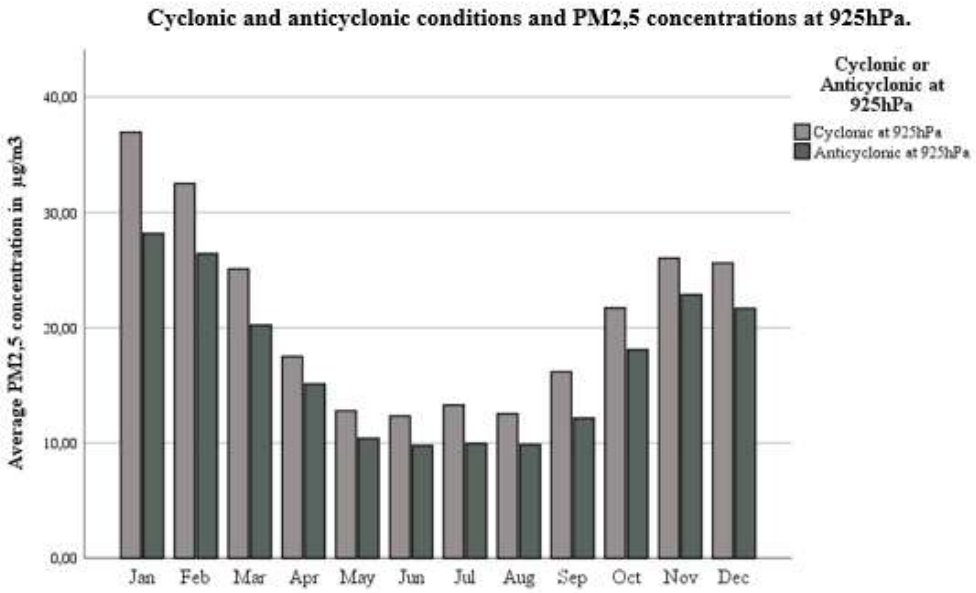

Figure 23: Bar diagram comparing PM2,5 concentrations for each month compared to each other depending on the cyclonic or anticyclonic conditions at 925hPa.

Figure 23 shows the distribution of the PM2,5 concentrations through the months while looking at the cyclonic or anticyclonic conditions. The figure shows that the PM2,5 concentrations are lower in summer than in winter months. The figure also shows that in each month the PM2,5 concentrations are higher under cyclonic conditions than under anticyclonic conditions at 925hPa. The output of the Mann-Whitney U test is shown in Appendix table 10, however, show that this difference is not significant ($p>0,05$). Thus, the PM2,5 concentration are not considered to be different under the different conditions.

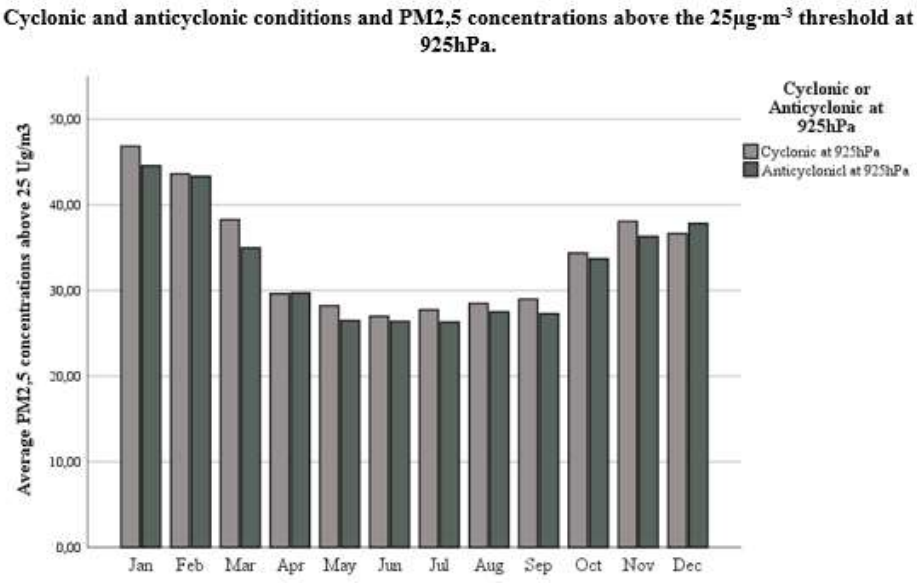

Figure 24: Bar diagram comparing PM25 concentrations above the 25µg·m^{-3}threshold for each month compared to each other depending on the cyclonic or anticyclonic conditions at 925hPa.

Figure 24 shows the average PM2,5 concentrations above the threshold for the cyclonic and anticyclonic conditions for each month. The figure shows that there PM2,5 concentrations are relatively similar under each of the conditions in all the months. The output of the Mann-Whitney U test in the Appendix table 10 shows that the PM2,5 concentrations above the threshold are significantly higher under anticyclonic conditions compared to the cyclonic conditions ($p<0,05$).

The results show that when looking at all the PM2,5 concentrations, there is no significant difference under the different conditions. However, when looking at the high PM2,5 concentrations measured at 925hPa, the anticyclonic conditions show significantly higher results.

3.1.3.4. Cyclonic or anticyclonic conditions and PM2,5 concentrations at 500hPa

Finally, the same process will be repeated, in order to test the PM2,5 concentrations at 500hPa.

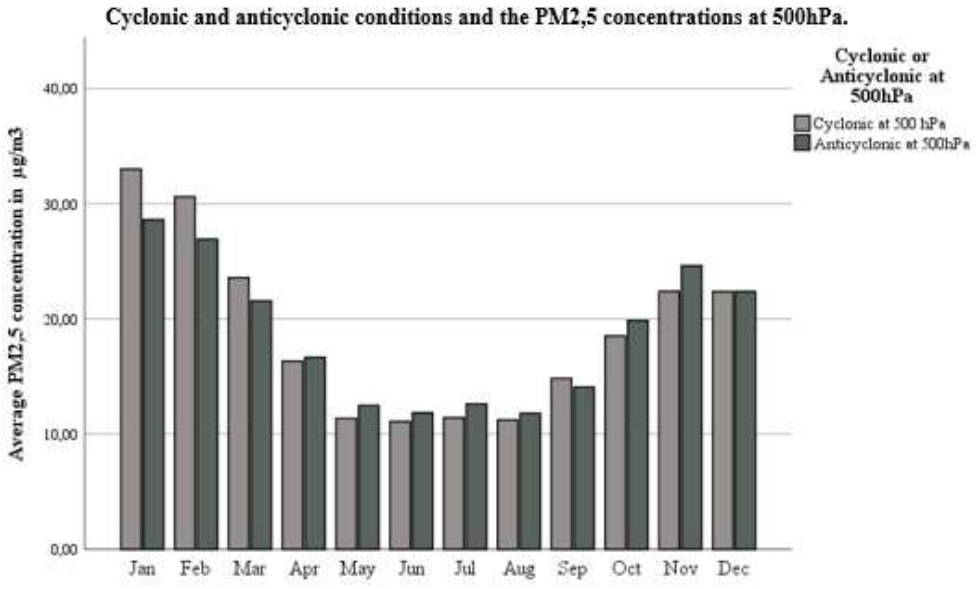

Figure 25: Bar diagram comparing PM2,5 concentrations for each month compared to each other depending on the cyclonic or anticyclonic conditions at 900hPa.

Figure 25 shows the distribution of the average PM2,5 concentrations under the cyclonic and anticyclonic conditions through the months. As has been observed in previous figures, the PM concentrations are lower in summer months than winter months. It can also be observed that in certain months the PM2,5 concentrations are higher under cyclonic conditions and some months the PM2,5 concentrations are higher under the anticyclonic conditions. In the Appendix table 10 the full output of the Mann-Whitney U test has been given, the results here show that there is no significant difference between the PM2,5 concentrations under the two weather conditions ($p>0,05$).

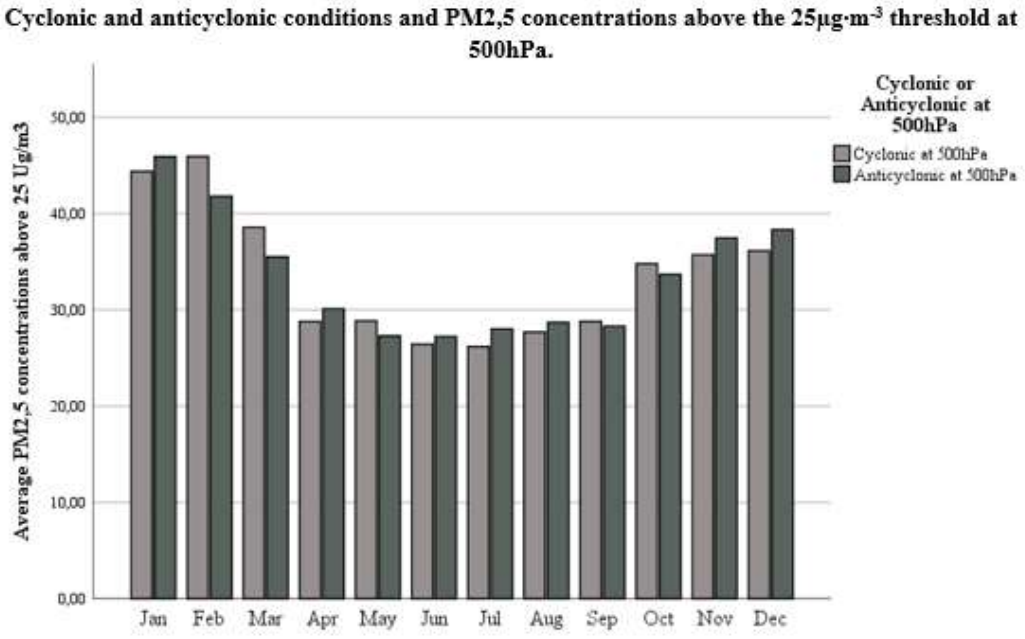

Figure 26: Bar diagram comparing PM25 concentrations above the 25µg·m^{-3}threshold for each month compared to each other depending on the cyclonic or anticyclonic conditions at 500hPa.

Figure 26 shows the distribution of the average PM2,5 concentrations that were measured above the threshold divided by cyclonic and anticyclonic conditions in each month. The figure shows that the PM2,5 concentrations are lower in summers than in winters. The figure also shows that there seems to be little difference between the cyclonic or anti cyclonic conditions at 500hPa. In the Appendix table 10 the output of the Mann-Whitney U test shows that this difference between the PM2,5 concentrations under the different weather conditions is not significant (p>0,05).

Thus, the results show that the cyclonic and anticyclonic conditions do not have a significant effect on the PM2,5 concentrations. Even when only looking at the high PM2,5 concentrations, no significant differences between the two could be found.

3.1.4. The impact of humidity conditions on PM concentration

Humidity is also one of the factors that has been analysed when looking at the meteorological effects on PM10 and PM2,5 concentrations. The distribution of the dry or wet conditions throughout a year is known to variate, due to temperature and seasonal changes. The yearly distribution of the humidity is shown in Figure 27, within the figure, there seems to be a small trend through the seasons. The wet humid conditions increase slightly within the summer and decrease in the winter months.

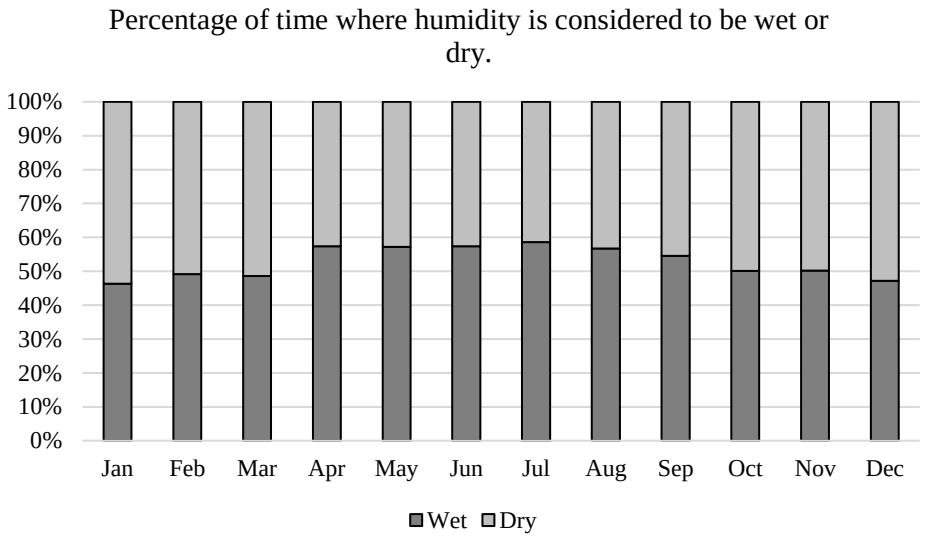

Figure 27: Percentage of the distribution where the conditions are considered to be wet or dry through the different months of the years .

The results in appendix A show that the PM concentrations that were measured during the measurement period were not normally distributed. Thus, the Mann-Whitney U test will be used to analyse the humidity data. This output is shown in appendix E.

3.1.4.1. Humidity and PM10 concentrations

In order to understand the differences in PM10 concentrations under the different humidity conditions, a figure will be given to show this difference and support the output found by the Mann-Whitney U test.

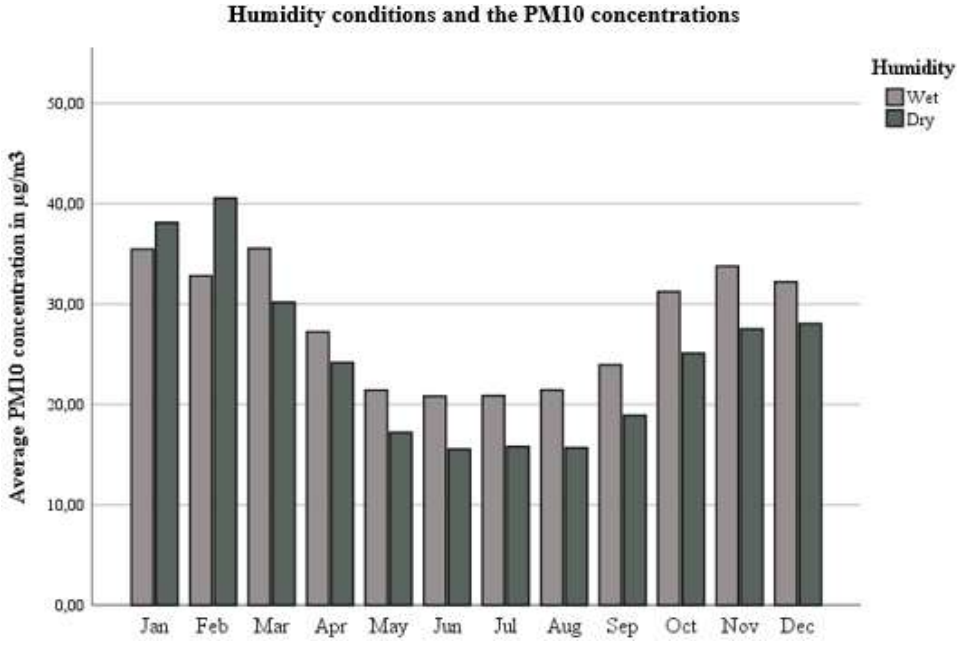

Figure 28: Bar diagram comparing PM10 concentrations for each month compared to each other depending on wet or dry humidity conditions.

Figure 28 shows the output for the bar diagram, looking at the PM10 concentrations within different months, divided by the wet and dry humidity conditions. When looking at the figure for all months, except January and February, the PM10 concentrations are higher under wet conditions. When looking at Appendix table 11 the output of the Mann-Whitney U test shows that the PM10 concentrations are significantly higher under wet conditions (p>0,05).

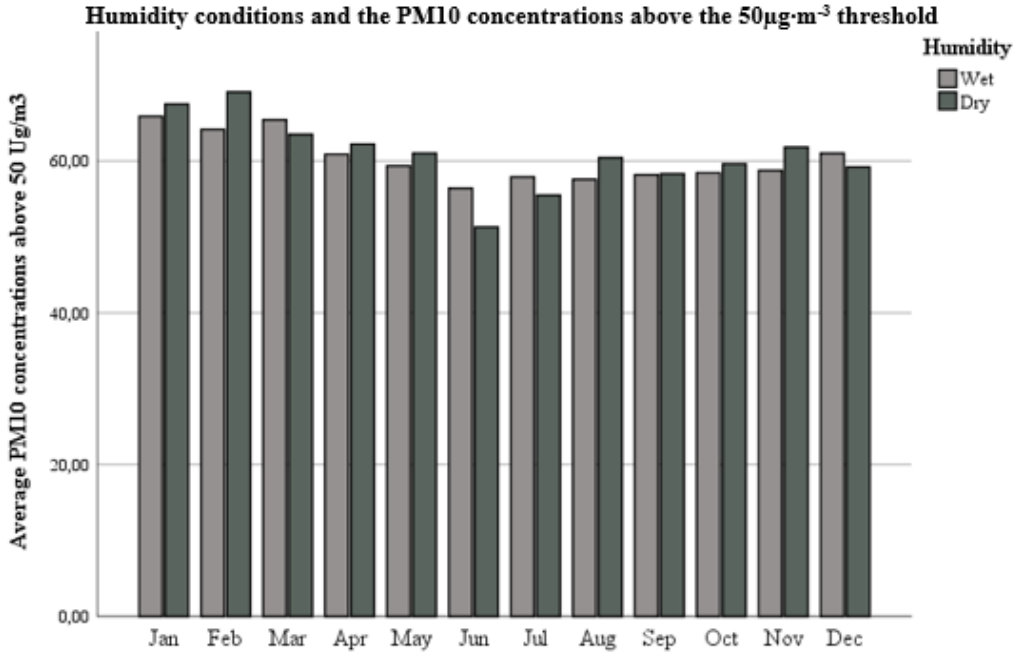

Figure 29: Bar diagram comparing PM10 concentrations above the threshold for each month compared to each other depending on wet or dry humidity conditions

Figure 29 shows a bar diagram looking at the PM10 concentrations that have been measured above the threshold concentration under the different months divided by wet or dry humidity conditions. The figure does not show clearly under which of the two conditions the PM10 concentrations are highest. In Appendix table 11 the output of the Mann-Whitney U test shows that the PM10 concentrations are significantly higher under dry conditions than under wet conditions (p<0,05).

Thus, the humidity conditions have a significant effect on the PM10 concentrations. When looking at all the PM10 concentrations measured, it seems that the PM10 concentrations are significantly higher under wet humidity conditions than under dry humidity conditions. When looking at the PM10 concentrations measured above the threshold concentration, it seem that the highest PM10 concentrations can be found under dry conditions.

3.1.4.2. Humidity and PM2,5 concentrations

Within this paragraph the effect of the humidity and the PM2,5 concentrations will be analysed.

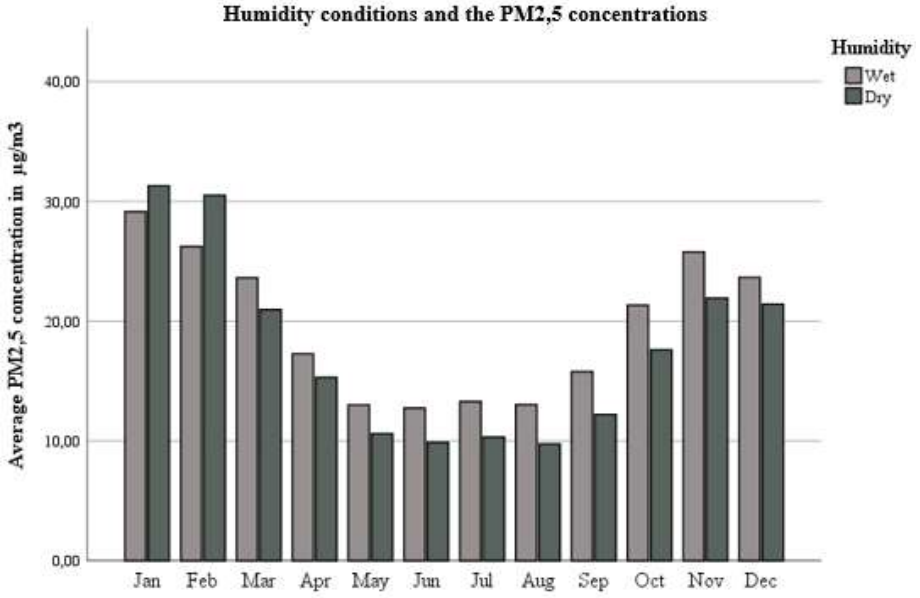

Figure 30: Bar diagram comparing PM2,5 concentrations for each month compared to each other depending on wet or dry humidity conditions.

Figure 30 shows the distribution of the PM2,5 concentrations under the different months divided by the wet and dry humidity conditions. As has been previously observed with the PM10 concentrations, the PM2,5 concentrations seem to be higher under wet conditions in all months except January and February. When looking at the output of the Mann-Whitney U test in Appendix table 11, it shows that the PM2,5 concentration is significantly higher under the wet conditions than under the dry conditions ($p<0,05$).

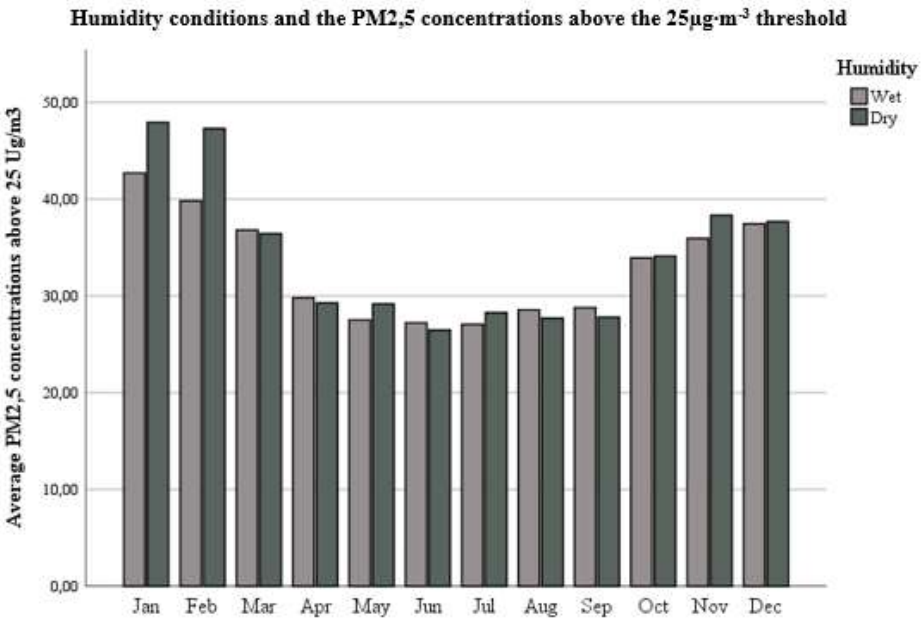

Figure 31: Bar diagram comparing PM2,5 concentrations above the threshold for each month compared to each other depending on wet or dry humidity conditions

Figure 31 shows the PM2,5 concentrations that were measured above the threshold for each month as a function of wet or dry humidity conditions. Appendix table 11 shows the output for the Mann-whitey U test, which shows that the PM2,5 concentrations are significantly higher under dry conditions than under wet humidity conditions ($p<0,05$).

Thus, as was observed with the PM10 concentrations, the PM2,5 concentrations are similar. When looking at all the PM2,5 concentrations, the highest concentrations can be found under wet conditions. When looking at only the high PM2,5 concentrations, the highest results can be found under the dry conditions.

3.1.5. The impact of precipitation on PM concentration

The precipitation amounts are closely linked to the humidity levels. However, the data on the precipitation gives more information on the actual rain fall events and amounts. In order to show how the humidity and the precipitation are related, Figure 32, shows the average precipitation per month, as expected the dry humidity levels have lower precipitation and the wet humidity levels have high precipitation. The figure also shows, just like was observed before, that the summer months have higher precipitation (as well as wet humidity levels) than the winter months.

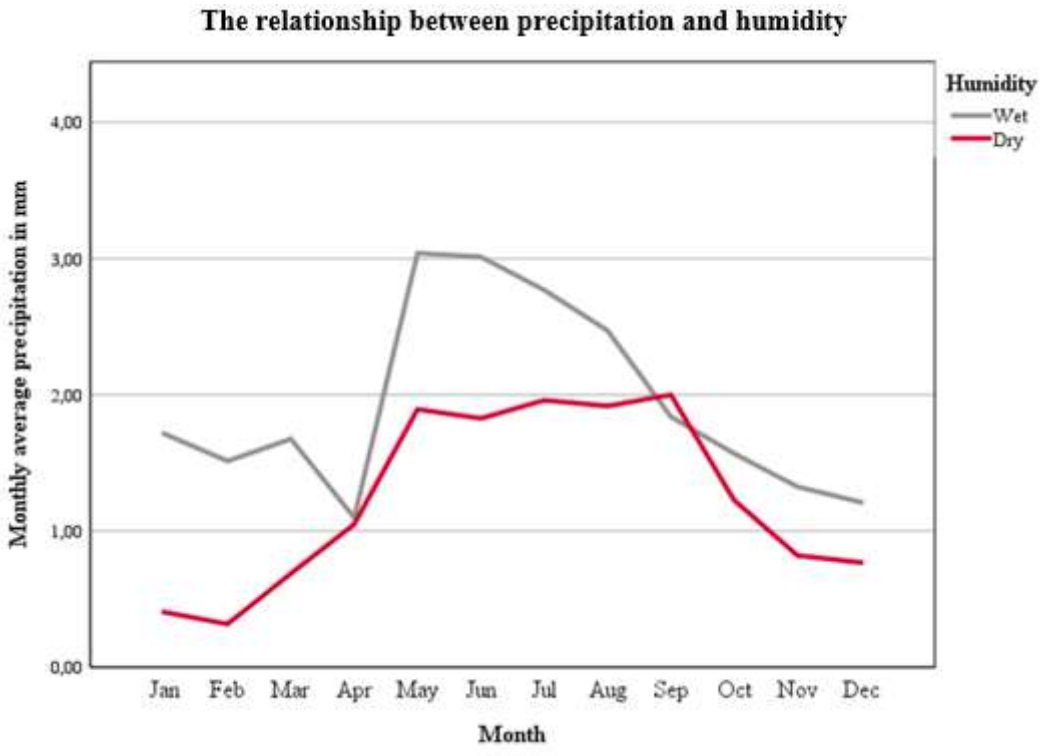

Figure 32: The daily average precipitation in mm per month separated into the dry and wet humidity groups.

In order to know what test to use for the correlation between PM concentrations and the precipitation, the precipitation needs to be tested to see if the data is normally distributed. In Appendix F the Kolmogorov-Smirnoff test has been performed. The data shows that the measured wind speed is

nonparametric. As Appendix A shows that the PM concentrations are also nonparametric, the Spearman's rho correlation will be used.

3.1.5.1. Precipitation and PM10 concentrations

Figure 33 shows a scatter plot that looks at the average PM10 concentrations and the daily average precipitation in mm.

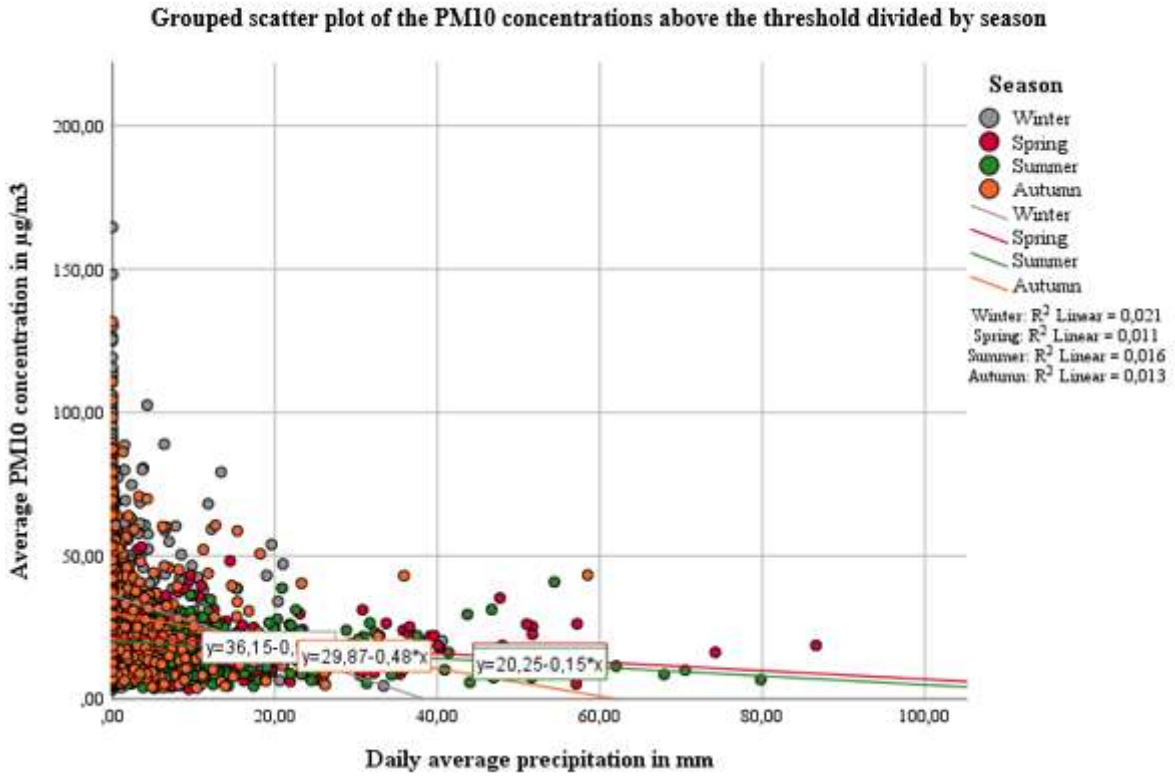

Figure 33: Scatter plot of the average PM10 concentration and the daily average precipitation in mm.

The scatter plot in Figure 33 shows that the concentrations are largely clustered in the bottom left corner, with some outliers, the data does not seem to be correlated in any of the seasons (winter linear R^2 = 0,021, spring linear R^2 =0,001, summer linear R^2 =0,016, autumn linear R^2 = 0,013). As there is are a large amount of observations, the use of the Spearman's correlation can better determine how big the correlation is and this correlation is significant.

Table 13: Output from the Spearman's rho correlation on the average PM10 concentrations and the daily average precipitation in mm.

			Average PM10 concentration in $\mu g \cdot m^{-3}$	Daily average precipitation in mm
Spearman's rho	Average PM10 concentration in $\mu g \cdot m^{-3}$	Correlation Coefficient	1,000	-0,228[a]
		Sig. (2-tailed)	-	0,000[a]
		N	5992	5871
	Daily average precipitation in mm	Correlation Coefficient	-0,228[a]	1,000
		Sig. (2-tailed)	0,000[a]	-
		N	5871	6675

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 13, shows the output of the Spearman's rho correlation between the average PM10 concentrations and the daily average precipitation in mm. The table shows that there is a weak negative correlation between the two that is considered to be significant (R_S= -0,228, n = 5992, p<0,05). The same will be analysed for the PM10 concentrations that have been measured above the threshold concentrations.

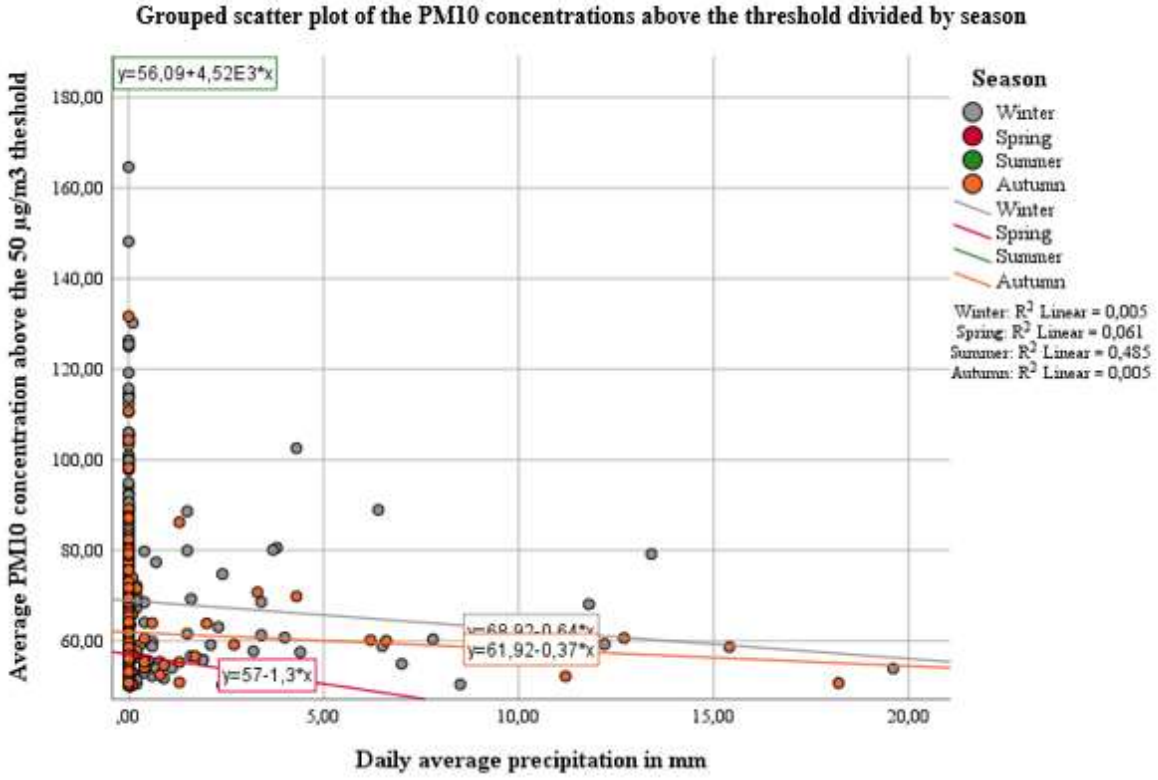

Figure 34: Scatter plot of the average PM10 measured above the threshold concentration and the daily average precipitation in mm divided by seasons.

Figure 34, shows the scatter plot of the average PM10 concentrations that have been measured above the threshold concentrations and the daily average precipitation in mm. the plot shows that there is a weak correlation between the two in any of the two seasons (winter linear R^2= 0,005, spring linear R^2= 0,061, autumn linear R^2= 0,005). Except when looking at the summer season, within summer a moderate correlation can be found between the two (summer linear R^2= 0,485). The reason for this higher correlation within summer seems to be due to the fact that the daily average precipitation was low within summer when looking at the high PM10 concentrations. Furthermore, a small amount of observations made within the summer season that had high PM10 concentrations and high daily average precipitation. This leads to an increase in the data clustering within the left side of the figure. Due to the fact that there was such a small amount of observations made within the summer season, all the PM concentrations that have been measured within the seasons will be analysed together with the Spearman correlation.

Table 14: Output from the Spearman's rho correlation on the average PM10 measured above the threshold concentrations and the daily average precipitation in mm.

			Average PM10 concentrations above 50 µg·m^{-3}	Daily average precipitation in mm
Spearman's rho	Average PM10 concentrations above 50 µg·m^{-3}	Correlation Coefficient	1,000	0,070
		Sig. (2-tailed)	-	0,017[a]
		N	1175	1175
	Daily average precipitation in mm	Correlation Coefficient	0,070	1,000
		Sig. (2-tailed)	0,017[a]	-
		N	1175	1175

[a] The correlation is significant at the 0,05 level (2-tailed).

Table 14 shows the output for the Spearman's rho correlation between the average PM10 concentrations above the threshold concentrations and the daily average precipitation in mm. The results show that there is a very weak correlation between the two and that this result is significant (R_S = 0,070, n = 1175, p<0,05).

The results for this analysis show that the daily average precipitation have a weak negative correlation with the PM10 concentrations that have been measured. When looking at the PM10 concentrations that were measured above the threshold concentrations there also seems to be only a very weak correlation between the two.

3.1.5.2. Precipitation and PM2,5 concentrations

Similar analysis will be done within this chapter, but here the PM2,5 concentrations will be analysed.

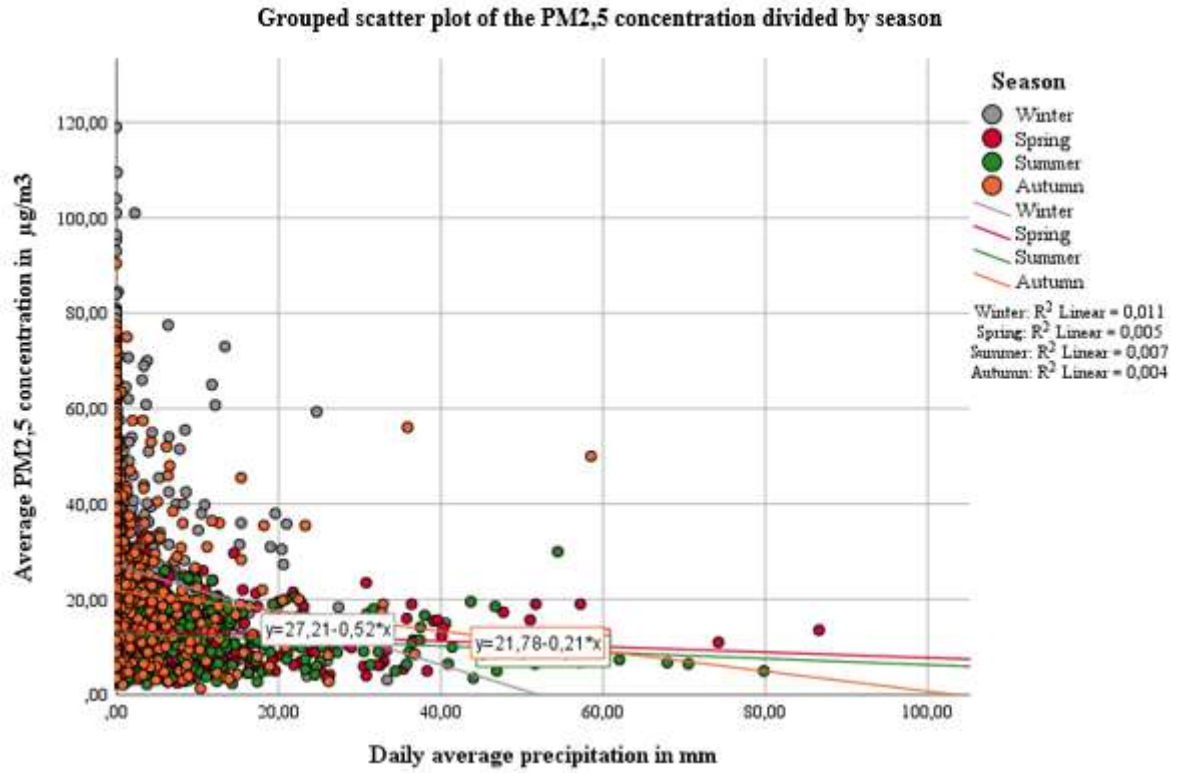

Figure 35: Scatter plot of the average PM2,5 concentration and the daily average precipitation in mm divided by season.

Figure 35, shows the scatter plot of the average PM2,5 concentrations and the daily average precipitation in mm. The plot shows a lot of similarities to the plot of the PM10 concentrations in Figure 33. The data are mostly clustered in the lower left corner. The results indicate that there is a very weak to no correlation between the two (winter linear R^2 = 0,011, spring linear R^2 = 0,005, summer linear R^2 = 0,007, autumn linear R^2 = 0,004). A large part of the data is clustered within the lower left corner, as was observed before with the PM10 concentrations.

Table 15: Output from the Spearman's rho correlation on the average PM2,5 concentrations and the daily average precipitation in mm.

			Average PM2,5 concentration in µg·m^{-3}	Daily average precipitation in mm
Spearman's rho	Average PM2,5 concentration in µg·m^{-3}	Correlation Coefficient	1,000	-0,143[a]
		Sig. (2-tailed)	-	0,000[a]
		N	4876	4764
	Daily average precipitation in mm	Correlation Coefficient	-,143[a]	1,000
		Sig. (2-tailed)	0,000[a]	-
		N	4764	6675

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 15, shows the output for the Spearman's rho correlation between the average PM2,5 concentrations and the daily average precipitation. The results show that there is significant but very weak negative correlation between the two (R_S = -0,143, n = 4764, p<0,01). Thus, it seems that the daily average precipitation has a weak negative correlation with the PM2,5 concentrations. The same analysis will be performed with the PM2,5 concentrations that are above the 25µg·m^{-3} threshold concentrations.

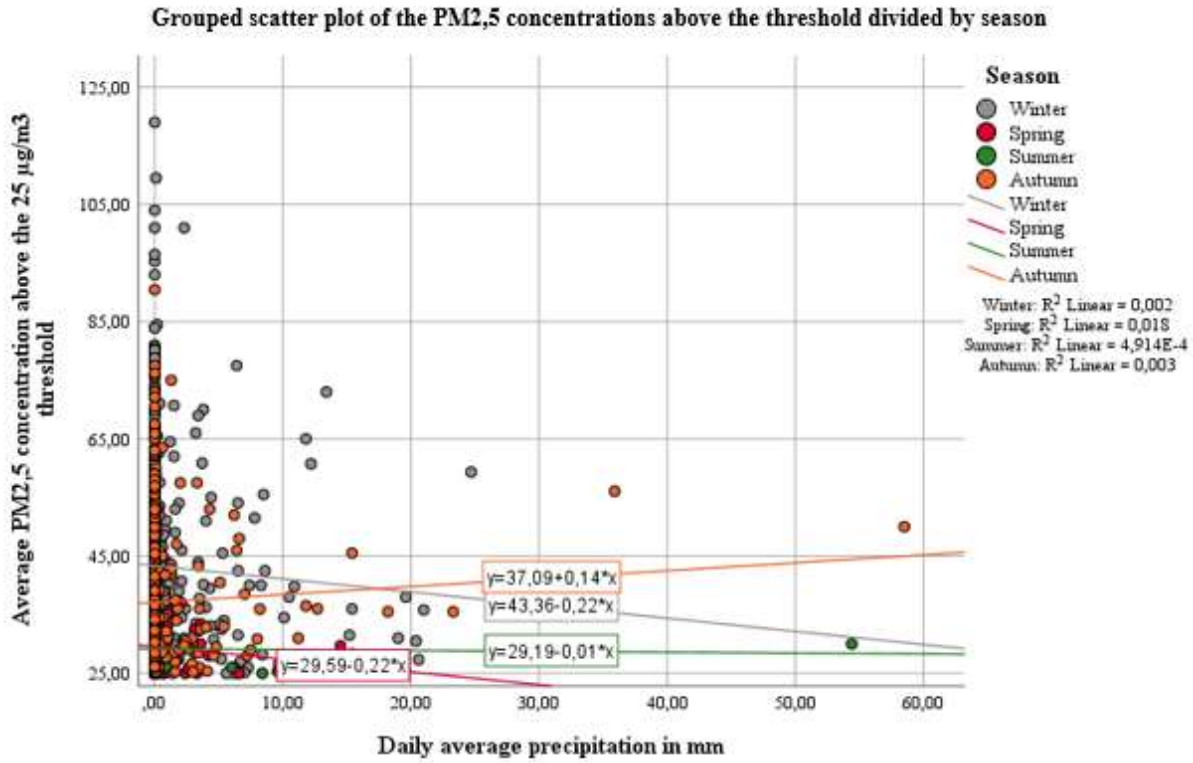

Figure 36: Scatter plot of the average PM2,5 measured above the threshold concentration and the daily average precipitation in mm divided by season.

Figure 36, shows the scatter plot of the PM2,5 concentrations that were measured above the threshold and the daily average precipitation. The plot shows that there is a very weak or even no linear correlation between the two in any of the seasons (winter linear R^2 = 0,002, spring linear R^2 =0,018, summer linear R^2 = 4,914·10^{-4}, autumn linear R^2 = 0,003). A large amount of the observed concentrations is located within the lower left corner of the plot. The spearman's rho correlation will give further information on this potential correlation.

Table 16: Output from the Spearman's rho correlation on the average PM2,5 concentrations above the threshold concentration and the daily average windspeed in m/s.

			Average PM2,5 concentrations above 25 µg·m^{-3}	Daily average precipitation in mm
Spearman's rho	Average PM2,5 concentrations above 25 µg·m^{-3}	Correlation Coefficient	1,000	0,042
		Sig. (2-tailed)	-	0,133
		N	1307	1307
	Daily average precipitation in mm	Correlation Coefficient	0,042	1,000
		Sig. (2-tailed)	0,133	-
		N	1307	1307

[a] The correlation is significant at the 0,01 level (2-tailed).

Table 16 shows the output for the Spearman's rho correlations between the PM2,5 concentrations that were measured above the threshold and the daily average precipitation. The results show that there is no significant correlation (R_S=0,042, n=1307, p>0,05). Thus, it is expected that there is no monotonic correlation between the two.

The results show that when looking at all the PM2,5 concentrations, there is only a very weak correlation between the two, but this is significant. When looking at the PM2,5 concentrations that were measured above the threshold it shows that there was no significant correlation found between the two.

3.2. The impact of spatial distribution on PM concentrations

The second part of this research will focus on the spatial distribution of the particulate matter concentrations. For this part of the research data has been collected in the Green Prater, this has been done on different days within two periods. The days that data was collected within the first period were the 12th of March, the 17th of March and lastly the 25th March. Within the second period there was a larger time difference between the days on which the data was collected. This was due to the large amount of rain within the period and issues with the PM sensor. The days on which measurements for the second period were taken were the 8th of May, the 20th of May, and the 29th of May.

In order to know what tests will be used to analyse the PM concentration data, the PM data needs to be tested for normal distribution. Appendix G , shows the output for the Kolmogorov-Smirnoff test. The results show that the PM10 and the PM2,5 concentrations are not normally distributed.

Table 17: The average PM10 and PM2,5 concentration and the amount of measurements per period, date, and round. All rounds have a code that shows the period that the measurements were taken, as well as the date and the round on that date.

Period	Date	Round code	Average PM10 concentration	Average PM2,5 concentration	N	% of Total N
1	12-Mar-20	P1D1R1	9,8895	1,4481	592	7,5%
		P1D1R2	6,9303	1,3010	782	9,9%
		Total	8,2053	1,3644	1374	17,4%
	17-Mar-20	P1D2R1	17,8651	6,6078	733	9,3%
		P1D2R2	24,0667	8,8545	765	9,7%
		Total	21,0321	7,7551	1498	19,0%
	25-Mar-20	P1D3R1	10,1629	3,8085	733	9,3%
		P1D3R2	12,4045	4,4121	1498	19,0%
		Total	11,2643	4,1051	1411	18,2%
		Total period 1	13,6824	4,4997	4313	54,6%
2	08-May-20	P2D1R1	19,0464	7,7782	742	9,4%
		P1D1R2	10,5188	4,3499	783	9,9%
		Total	14,6679	6,0180	1525	19,3%
	20-May-20	P2D2R1	7,0651	3,4533	272	3,4%
		P2D2R2	9,3865	4,0663	587	7,4%
		Total	8,6515	3,8722	859	10,9%
	29-May-20	P2D3R1	8,2764	2,7348	399	5,0%
		P2D3R2	10,9898	3,8330	806	10,2%
		Total	10,0914	3,4694	1205	15,2%
		Total period 2	11,6814	4,6487	3589	45,4%

Table 17, shows the distribution of the measurements over the different periods and days. Due to some technical issues there are slightly more measurements taken in the first period than in the second period. The table shows that the average PM10 concentrations that have been measured within period one were slightly higher than the average PM10 concentrations in period 2. The average PM2,5 concentrations for both periods were similar.

3.2.1. The impact of location on the PM concentration

The PM10 and PM2,5 concentrations differ over different locations, due to the characteristics of the locations. The measurements were taken on the six days on the same route. The results of the PM10 and the PM2,5 concentrations that have been measured on all the days is shown in the maps in Appendix H.

Figure 37A: ArcMap of the PM10 concentration distribution in period 1 on day 2 round 1 (P1D2R1).
17-03-2020

Figure 37C: ArcMap of the PM10 concentration distribution in period 1 on day 2 round 2 (P1D2R2).
17-03-2020

Figure 37C: ArcMap of the PM2,5 concentration distribution in period 1 on day 2 round 1 (P1D2R1).
17-03-2020

Figure 37D: ArcMap of the PM2,5 concentration distribution in period 1 on day 2 round 2 (P1D2R2).
17-03-2020

Figure 37: The maps with the PM10 and PM2,5 concentrations measured on the second day of period 1.

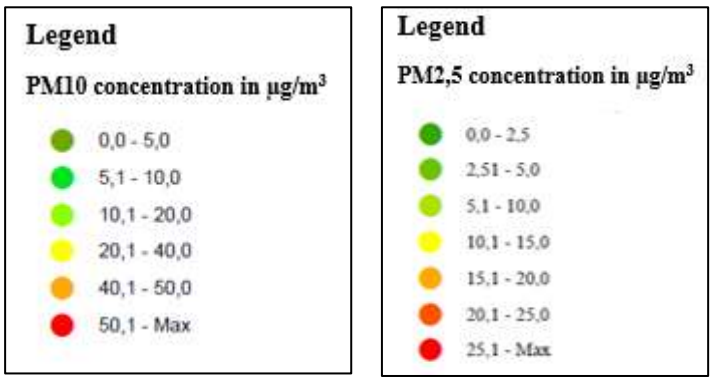

Figure 38: legend for the figures displayed in Figure 37.

Figure 37 shows the visual representation of the analysed route. The figure shows the PM10 and PM2,5 concentrations. The legend of the figure is shown in Figure 38. This day was chosen to discuss in further detail as there is less data missing, as appendix H shows, there is data missing in certain rounds. The figure shows that at certain points, the PM concentrations are higher than at other points. Figure 37A, B and D show that near the highway (A23), the PM concentrations show higher results than the other locations, this will be analysed into further detail in Figure 39 and Figure 40.The figure shows that the PM concentrations appear to be lower within the first round of the day, compared to the second round of the day. This is especially visible when comparing Figure 37C and Figure 37D.

In order to analyse to what extent, the spatial distribution influence the PM concentration, 3 different locations were analysed and compared to each other, the three different locations will be addressed as park, for location number 1, highway for location number 2 and road for location number 3. As Appendix G, shows the collected data is not normally distributed. Thus, the Mann-Whitney U test has been used to analyse the data from the different locations, the output is shown Appendix I .

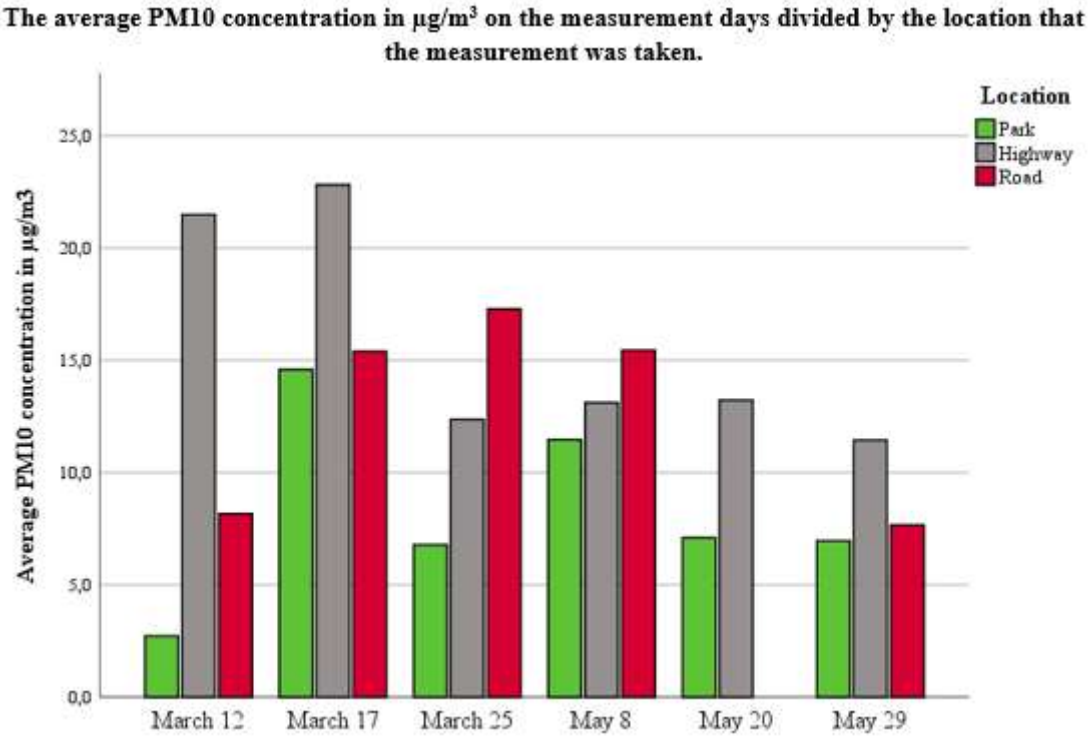

Figure 39: The average PM10 concentrations on the measurement days at the specific measurement locations.

Figure 39 shows a visual representation of the PM10 concentrations that have been measured over the different days and the different locations where the measurements were on the route. The figure shows that the lowest PM10 concentrations have been measured within Prater park, the figure also shows that the highest measured PM10 concentrations were either while crossing the highway A23 or on the smaller road. The figure shows that overall, the PM10 concentrations were higher within the first days and lower in the last days. There were no measurements on the road on the 20th of May as the PM sensor

malfunctioned. When looking at Appendix I, Appendix table 14, it can be seen that the highest measurements were made beside the highway, here the PM10 concentrations are significantly higher than the PM10 concentrations in the park and on the smaller road (p>0,05). The result also show that the significantly lowest PM10 concentrations have been measured in Prater park.

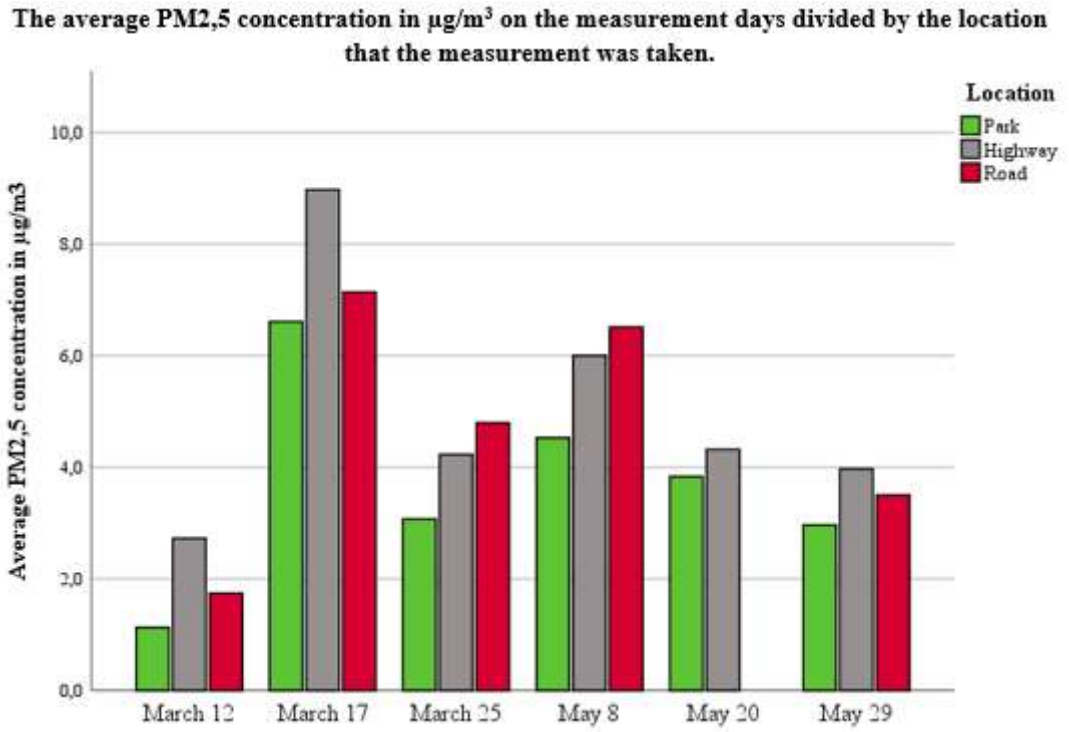

Figure 40: The average PM2,5 concentrations on the measurement days at the specific measurement locations.

Figure 40 shows the visual representation of the PM2,5 concentrations that have been measured within the different locations. The figure shows that on most days, the PM2,5 concentrations were highest beside the highway A23. On the 25th of March and the 8th of May, the PM2,5 concentrations on the smaller road were higher than the highway, as was previously observed with the PM10 measurements. As was observed with the PM10 measurements, due to the malfunction of the PM sensor on the 20th of May, there is no road data available. When looking at Appendix table 15, it shows that the PM2,5 concentrations measured beside the highway are significantly higher than the PM2,5 concentrations measured in the park (p<0,05). However, there is no significant difference between the PM2,5 concentrations measured beside the highway and on the road (p>0,05). The PM2,5 concentrations measured on the road were higher than the PM2,5 concentrations measured within the park (p<0,05).

Thus, the results show that the lowest PM10 and PM2,5 concentrations can be found within the park. The highest PM10 concentrations are found beside the highway A23 and there is no significant difference between the different roads when looking at the PM2,5 concentrations.

3.2.2. The impact of time on the PM concentration

Temperature inversion is an important aspect when looking at PM concentrations. One of the easiest ways to analyse temperature inversion is the time at which the measurement was taken. This leads to PM concentrations that are generally higher in mornings than in evenings. To take optimal advantage of the potential temperature inversion. To analyse whether temperature inversion influences the measured data that has been collected, the two rounds that have been measured each day will be analysed. As Appendix G shows the data is non-parametric, thus, the two rounds on each day will be compared to each other using the Mann-Whitney-U test.

Table 18: Summarized output for the Mann-Whitney U test to analyse the significant differences between the PM10 and PM2,5 concentrations in the different rounds of data taken within a day.

	PM10 concentration		PM2,5 concentration	
	Asymp. Sig. (2-tailed)	Highest round	Asymp. Sig. (2-tailed)	Highest round
Period 1				
Day 1 *12-03-2020*	0,033 [a]	Round 2	0,436	-
Day 2 *17-03-2020*	0,000 [a]	Round 2	0,000 [a]	Round 2
Day 3 *25-03-2020*	0,000 [a]	Round 2	0,000 [a]	Round 2
Period 2				
Day 1 08-05-2020	0,000 [a]	Round 1	0,000 [a]	Round 1
Day 2 20-05-2020	0,000 [a]	Round 2	0,000 [a]	Round 2
Day 3 29-05-2020	0,000 [a]	Round 2	0,000 [a]	Round 2

[a] Significant difference are displayed at 0,05 level.

The full output of the Mann-Whitney U test is shown in Appendix J. Table 18 shows the summary of the Mann-Whitney U test. The results show that when looking at the PM10 data, on all the days except the 8th of May 2020 (first day of period two) the data collected in the second round of the day is significantly higher than the data collected within the first round of the day ($p<0,05$). Thus, meaning that this increase of PM10 concentration is not due to temperature inversion as this would most likely cause the first round of the day to have the highest PM10 concentrations. However, the rush hour in

Vienna starts at about 08.00, at the same time as that the second round was made. Thus, the increased use for vehicle and traffic on the roads could lead to the higher PM10 concentrations at this point in the morning.

When looking at the PM2,5 data, the data on the 12th of March 2020 (first day of period one) shows that there are no significant differences between the two rounds ($p>0,05$). All the other days show that there is a significant difference between the two rounds ($p<0,05$). Just like with the PM10 concentrations on the, 8th of May 2020 (first day of period two) the data collected in the first round is higher than in the second round. On all the other days that data was collected, the data collected in the second round is significantly higher than in the first round. Thus, here too, it seems that the main cause for the higher PM2,5 concentrations in the second round are not due to temperature inversion but could be due to the increased traffic after the rush hour.

3.2.3. The impact of meteorological conditions on the PM concentration

As has been observed previously, the meteorological conditions can affect the PM concentrations significantly, certain meteorological conditions have higher impact on PM concentrations than others. Even though much care was taken that the data was collected on days with similar meteorological conditions, there were still differences in the meteorological conditions between the different days. In order to see if the meteorological conditions occurring on the different days have an impact on the PM concentrations, the different days will be compared to each other. Appendix G shows the output for the Kolmogorov-Smirnoff test, and shows that the PM concentration data is not normally distributed. Thus, the Mann-Whitney U test will be used to analyse the data and compare the different days. The full output for the Mann-Whitney U test is shown in Appendix K, below the results of this test will be discussed into further detail.

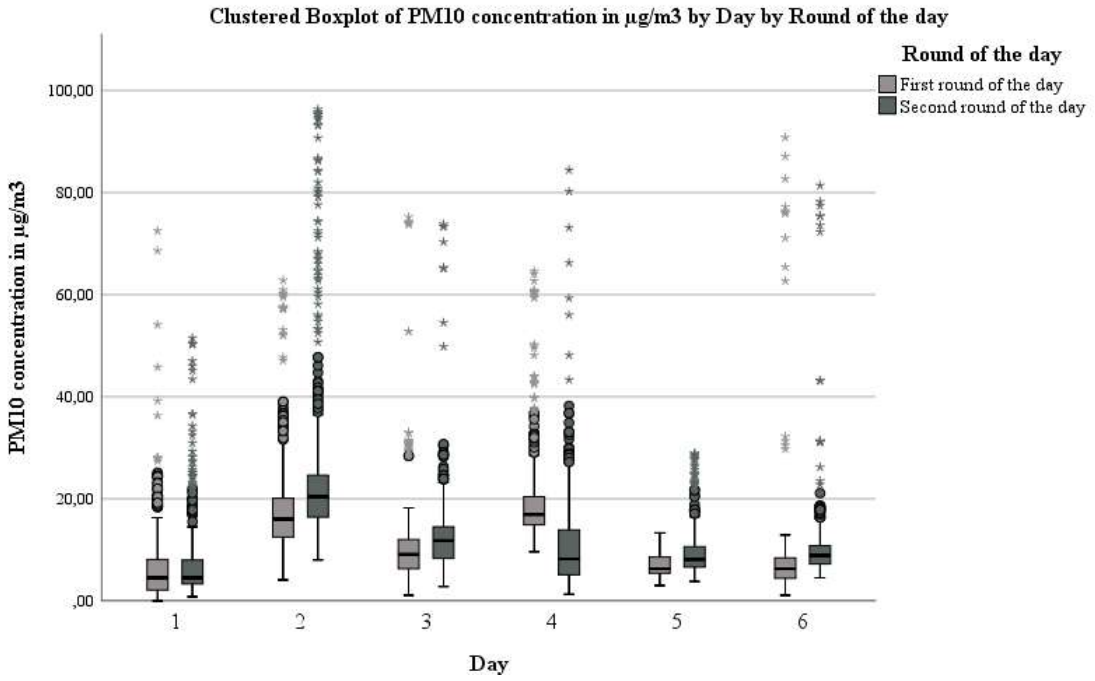

Figure 41: A boxplot showing the PM10 concentrations on the different days, divided by the rounds made on each day. Day 1, 2 and 3 were measured in period 1 and day 4,5 and 6 were measured in period 2.

Figure 41 shows the boxplot of the distribution of the PM10 concentrations within the different rounds of each day. There is a lot of variation in the PM10 concentrations that have been measured over the different days. The figure clearly shows that the highest concentrations were measured on the second day. The figure also shows that the lowest mean PM10 concentrations were measured on day 1, 5 and 6. Table 19 shows the summarized output for the Mann-Whitney U test that looks at the comparison of the PM10 concentrations measured on each day that measurements were taken.

Table 19: Summery of the Mann-Whitney U test for comparing the PM10 concentrations measured on the measurement days to each other.

		Period 1			Period 2		
Day		1	2	3	4	5	6
Period 1	1						
	2	Day 2					
	3	Day 3	Day 2				
Period 2	4	Day 4	Day 2	Day 4			
	5	Day 5	Day 2	Day 3	Day 4		
	6	Day 6	Day 2	Day 3	Day 4	-	

Table 19 shows that the highest PM10 concentrations were measured on the second day in the first measurement period (17th of March). The second highest PM10 concentrations were measured on the first day in the second measurement period (8th of May) followed by the third day in the first measurement period (25th of March), and the second and third day in the second measurement period,

who showed no significant differences (20th of May and 29th). The lowest PM10 concentrations were measured on the first day in the first measurement period (12th of March).

The meteorological condition of the different measurement days can be found in Appendix L. Within paragraph 2.1, the results showed that wind direction, cyclonic or anti cyclonic conditions at 925hPa and 500hPa and humidity conditions have a significant impact on the PM10 concentrations. The results in Table 19 show that the highest PM10 concentrations have been measured on the second day in the first measurement period, the 17th of March. Appendix table 23 shows that on this day the wind direction was from north/eastern direction. The wind speed was 4,9 m/s which was the lowest daily average wind speed that had been measured on all of the measurement days. At 925hPa cyclonic conditions occurred and at 500hPa anticyclonic conditions occurred. The humidity conditions were wet and like all the other measurement days, there was no precipitation. Thus, it seems that these meteorological conditions lead to significantly higher PM10 concentrations. When comparing this to the results from the paragraph 2.1, the results show that significantly higher PM10 concentrations were measured under eastern, south/eastern and southern winds, cyclonic conditions at 925hPa, anticyclonic conditions at 500hPa and wet humidity. Wind speed and precipitation did not have a significant effect on the PM10 concentrations. Although the wind direction measured on the 17th of March does not match the wind direction that causes the highest PM10 concentrations within the paragraph 2.1, of this research, however, the cyclonic conditions as well as the humidity conditions do match up with the highest PM10 concentrations found within the paragraph 2.1.

The lowest PM10 concentrations were measured on the 12th of March. Appendix table 23 in appendix L shows the meteorological conditions of this day. The wind came from north/eastern direction and the wind speed was 13,51 m/s, which is the fastest wind speed measured during all the measurement days. At both 925hPa and 500hPa anticyclonic conditions occurred and the humidity conditions were dry. Lastly, there was no precipitation during this day. The results in paragraph 2.1, , showed that north/eastern winds lead to low PM10 concentrations. This is a phenomenon that seems to also occur within the mobile measurement results. Lower PM10 concentrations were observed under anticyclonic conditions at 925hPa and cyclonic conditions at 500hPa, only the anticyclonic conditions at 925hPa seem to have had an effect on the low PM10 concentrations here. The dry humidity conditions were shown to lead to lower PM10 concentrations, as is the case here. Thus, the wind direction, the anticyclonic conditions at 925hPa and the humidity conditions on this day proved to show similar low PM10 concentrations as were found within paragraph 2.1.Appendix table 22, the full output of the Mann-Whitney U test can be seen. When looking at the PM10 concentrations that were measured in the first measurement period in March, the concentrations are significantly higher than the concentrations measured in the second measurement period in May ($p<0,05$). This is a logical result as the PM concentrations are lower within the warmer months of a year compared to the colder months of the year.

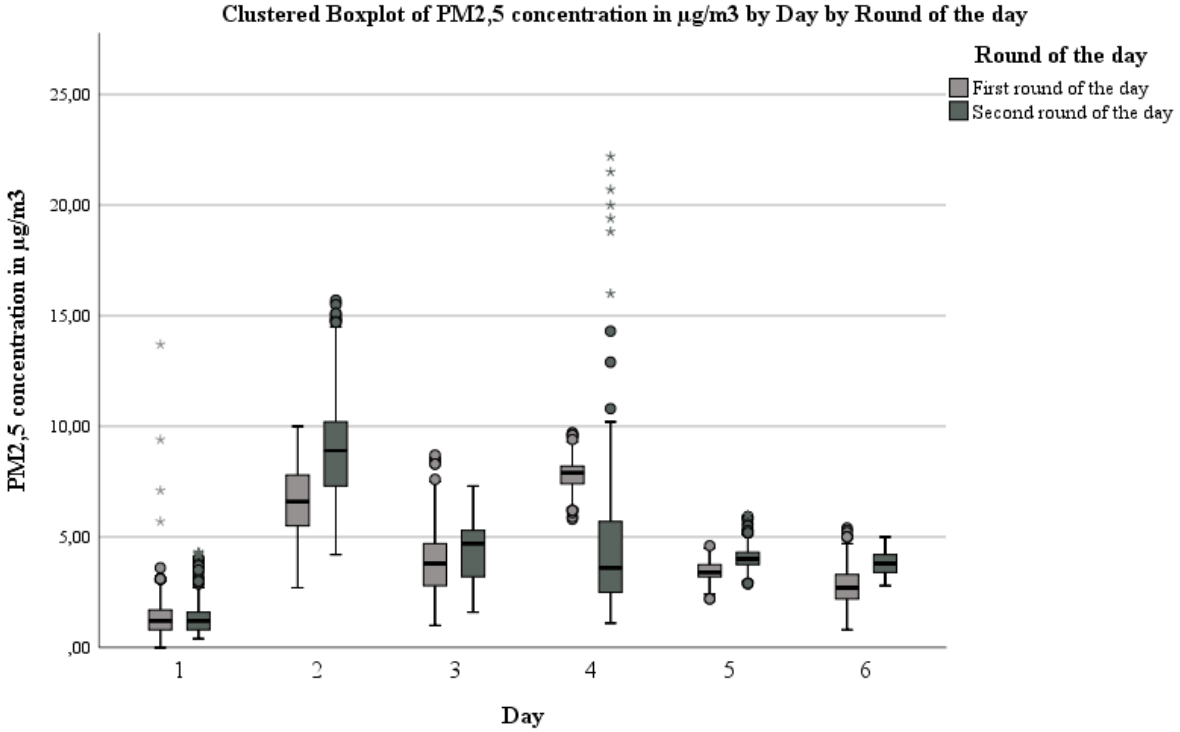

Figure 42: A boxplot showing the PM2,5 concentrations on the different days, divided by the rounds made on each day. Day 1, 2 and 3 were measured in period 1 and day 4,5 and 6 were measured in period 2.

Figure 42 shows the distribution of the PM2,5 concentrations on all the days of the measurement period. The figure shows that the Pm2,5 concentrations do not variate as much as the PM10 concentrations. The figure shows that the highest PM2,5 concentrations seem to have been measured on day 2 and day 4. The lowest PM2,5 concentrations were on the first day, and on day 5 and 6.

Table 20 shows the summarized output for the Mann-Whitney U test that looks at the comparison of the PM10 concentrations measured on each day that measurements were taken.

Table 20: Summary of the Mann-Whitney U test for comparing the PM2,5 concentrations measured on the measurement days to each other.

		Period 1			Period 2		
Day		1	2	3	4	5	6
Period 1	1						
	2	Day 2					
	3	Day 3	Day 2				
Period 2	4	Day 4	Day 2	Day 4			
	5	Day 5	Day 2	Day 3	Day 4		
	6	Day 6	Day 2	Day 3	Day 4	Day 5	

Table 20 shows that the lowest PM2,5 concentrations have been measured on the first day of the first measurement period (12th of March). This is followed by the second lowest PM2,5 concentrations

measured on the third measurement day in period two (29th of March) and the third lowest on the second day of the second period (20th of March). The highest PM2,5 concentrations were measured on the second day of the first period (17th of March) followed by the third (25th of March) and the first day of the first period (8th of May).

As has been observed with the PM10 concentrations, the highest PM2,5 concentrations were measured on the 17th of March. The paragraph 2.1, The impact of meteorological conditions on the PM concentrations showed that the highest PM2,5 concentrations are found with eastern, south/eastern, and southern winds and wet humidity conditions. All the other meteorological conditions that were analysed did not show significant results within the paragraph 2.1. On the 17th of March, the wind direction was from north/eastern direction, thus not in line with the wind directions causing the highest PM2,5 concentrations within paragraph 2.1The impact of meteorological conditions on the PM concentrations. The wet humidity conditions that were observed were in line with the results from the paragraph 2.1.

The lowest PM2,5 concentrations were measured on the 12th of March. The measured wind direction was north/east, which has been shown to lead to low PM2,5 concentrations. On this day, the humidity conditions were dry, this has been shown to lead to lower PM2,5 concentrations. The other meteorological conditions did not have a significant effect on the PM2,5 concentrations within this research.

When looking at the output of the Mann-Whitney U test in appendix K, Appendix table 22, it shows that the PM2,5 concentrations that have been measured are significantly lower in the first period of measurements in March compared to the second period of measurements in May ($p<0,05$). As found in the literature review and within the results in chapter 3.1, it seems unlikely that the PM2,5 concentrations are higher in the warmer months of the year than in the colder months.

4. Discussion

The results within this research have given reason to discuss certain aspects of the collection and analysis of the data and the outcome of the results.

One aspect of the used data that is important to address it that for the first part of the research, the data analysed was measured over a 20-year period. However, technology has changed a lot over this time period and thus, the data from the later years will be more exact than the data from the earlier years. This could impact the results. Within these results, the data for all the years was analysed as an average in order to get better results over the whole time period. The outcome of the different meteorological conditions within the first part of the research will be discussed in further detail.

The results of this research showed that the most frequent wind directions that occur in Vienna are south/west, west, and north/west winds and that the winds from the east, south, south/east and north occur the least frequently. The literature review shows that within Vienna north/western and south/eastern directions are most frequent (Stohl and Kromp-Kolb, 1994). It is also known that western wind directions are most frequent within central Europe. As expected, when looking at the results, the wind does occur most frequently from western direction. The literature review shows that eastern winds have been proven to be more polluted than the wind from other directions (Wonaschütz *et al.*, 2015). When looking at all the analysed PM concentrations during the measurement period, the results show that the highest PM10 concentration was measured with eastern, south/eastern and southern winds. The highest PM2,5 concentrations were measured with eastern, south/eastern and southern winds. This is largely as expected when looking at the literature review due to the higher pollutants from eastern winds. The higher pollutants in the southern winds within the Vienna winds are harder to explain but could potentially be attributed to larger industries within the city or this phenomenon could have occurred due to the combination of other meteorological conditions. There was no significant difference found between the eastern, south/east and southern winds and the PM10 and PM2,5 concentrations. The results were less apparent when looking at the high PM concentrations that were measured above the threshold concentration. Significant differences between the high PM concentrations and wind direction were made but no specific conclusions could be made thus indicating that high PM pollution episodes do not occur due to wind from a specific wind direction. It is advised that more research should be done on this area, looking at high PM concentration measured above a certain threshold concentration and wind directions. When looking at the different results between the PM10 and PM2,5 concentrations, wind direction is known to have a slightly higher impact on the PM10 concentrations than the PM2,5 concentrations (Puxbaum *et al.*, 2004). However, this was not clearly proven within this research. Within future research, this would need to be analysed in further detail. Taking into consideration the surrounding landscapes of Vienna, specifically the hilly terrains of the Wienerwald, the west of Vienna is known to have more south/western winds than the rest of the city (Stohl and Kromp-Kolb, 1994). As

only one average wind direction has been used for the entire city in this research, and the PM concentrations have been measured all over the city, this could have led to less accurate results, thus it is advised that more research is done looking at this issue.

Considering the results found when looking for correlations between wind speed and PM concentrations, both for PM10 and PM2,5 concentrations, only a very weak, however significant, correlation was found. This was not expected, as has been stated within the introduction, some studies suggest that there is a positive correlation between PM concentration and wind speed, thus meaning that when wind speed increases the PM concentration increases. Literature suggests that the reason for this is mostly due to increased dust concentrations within the atmosphere (Csavinaa *et al.*, 2014). However, other studies have found that there is a negative correlation between wind speed and PM concentration, thus meaning that when wind speed increases the PM concentrations decrease. This was explained by the fact that the increased wind dilutes the PM concentration (Freutel *et al.*, 2013). However, it has also been discussed that there are significant challenges when analysing the impact of wind speed on PM concentrations (Csavinaa *et al.*, 2014). Thus, this could explain why, within this research there were no strong correlations between the wind speed and the PM concentrations. A potential problem with these results could be that the wind speed used was only measured at the Institut für Meteorologie und Klimatologie at BOKU and the PM concentrations were an average of all the measurements of Vienna. The one measurement at BOKU assumes that the daily wind speed is equal all over Vienna, even if this is not always the case. Literature review shows that the location, urban, rural or other structural elements can have a large impact on the wind speed (Jones, Harrison and Baker, 2010). Thus, this could be the cause of the very weak correlation that was found within this research. In order to get a more precise outcome on this topic, more research is advised looking at the PM concentrations and the local wind speed.

When looking at the results of the cyclonic and anticyclonic conditions, the results show that at 500hPa, the anticyclonic conditions are more frequent throughout the year than the cyclonic conditions. This is similar to the trends observed all over Europe within the analysed literature (Demuzere *et al.*, 2009). PM concentrations are known to be higher under anticyclonic weather conditions (Makra *et al.*, 2007; Adamek and Ziernicka-Wojtaszek, 2017). Overall, differences between the different geopotentials are expected. When looking at the PM10 and PM2,5 concentrations and the cyclonic or anticyclonic conditions at 925hPa within the results, it is interesting that the PM10 concentrations are significantly higher under cyclonic conditions, this phenomenon seems to be equal through the year. This is an unexpected result. A potential explanation for this could be the fact that the cyclonic or anticyclonic conditions were measured at 925hPa and the cyclonic or anticyclonic indicators found in literature were measured at a different pressure. When looking at the high PM10 concentrations that were measured above the threshold concentration, no significant differences were observed. When looking at the PM2,5 concentrations, no significant differences were found between the two conditions. This result is also unexpected, and more research is necessary here in order to understand this outcome. However, when

looking at the high PM2,5 concentrations that were measured above the threshold concentration, the anticyclonic conditions show significantly higher results, as is expected. When looking at the high PM10 and PM2,5 concentrations, both showed no significant differences under the different meteorological conditions. Thus, within this research, the results were largely not as predicted. It is advised that more research will be done on this topic in order to get a better understanding.

When looking at the humidity levels, an important aspect that needs to be discussed is the fact that that the choice of dry and wet humidity levels has not been defined properly (Philipp *et al.*, 2010). The definition was that 'wet or dry conditions were defined by the weighting area mean of the value of precipitable water, which was then compared to the long-term daily mean'. This, however, does not give a clear definition of when a situation is wet or dry, and therefore the outcomes of the results could be unclear. Furthermore, when combining the humidity levels with the precipitation levels, the dry humidity conditions did not always occur during low precipitation events, just as wet humidity conditions did not always occur during high precipitation events as would have been expected. A potential reason for this is the different data origins of the humidity levels and the precipitation levels. The humidity levels are from the WLK data set for all of Austria whereas the precipitation concentrations is measured at Institut für Meteorologie und Klimatologie at BOKU. This could have led to a slight difference in the outcome. When looking at the outcome of the research on the humidity levels, interesting results can be found. When looking at all the PM concentrations, it was found that the PM10, as well as the PM2,5 concentrations, were higher under the wet conditions than under the dry humidity conditions. This is not entirely as expected. However, when looking at the literature review this can be explained by the fact that with mildly wet humidity levels, PM particles are known to enhance and thus, wet humidity conditions can lead to higher PM concentrations, as the humidity levels play an important part in the PM formation within the atmosphere (Gupta and Christopher, 2009). When looking at the results of the high PM10 and PM2,5 concentrations that were measured above the threshold, it seems that the PM concentrations were significantly higher under dry humidity conditions than wet humidity conditions. When looking at the literature research, this could be because increased humidity causes the PM concentrations to be washed out and thus reducing the PM concentrations. Under dry conditions, it is also known that dust and dirt occur more within the atmosphere and therefore increase the PM concentrations (Flocas *et al.*, 2009; Wang *et al.*, 2018). Thus, it can be said that within the results found within this research, the PM concentrations are higher under wet conditions when looking at all the PM concentrations. However, when looking at only the high PM concentrations, it seems that wet humidity levels decrease the PM concentrations, and the highest concentrations are found under dry humidity conditions.

When looking at the precipitation data, the results of the correlation between the precipitation and the PM concentrations within this research show that the relationship between precipitation and PM10 concentration is a weak negative correlation. And between precipitation and PM2,5 concentrations, there

is a very weak negative correlation. This means that with higher precipitation, the PM concentrations decrease. As shown in the literature review, the cause of this is due to the washout of the PM particles by the precipitation (Mircea, Stefan and Fuzzi, 2000). However, the correlation between the two is not strong. The reason for this is potentially similar to the problems occurring with the wind speed data. The precipitation data is only from the measurement station Institut für Meteorologie und Klimatologie at BOKU, whereas the PM concentration data is an average from all stations over Vienna. Precipitation can also be highly influenced by building and surrounding structure, this could impact the correlation (Blocken and Carmeliet, 2006). When looking at the high PM concentrations that were found above the threshold, different results were found. The PM10 concentrations measured above the threshold had a very weak positive correlation with the precipitation, and the PM2,5 concentrations above the threshold had no significant correlation with precipitation. This difference between the PM10 and PM2,5 concentrations is potentially due to the fact that precipitation reacts differently with different PM concentration sizes (Zhang *et al.*, 2018). However, this does not explain why there is a positive correlation. A reason could be that the data were not collected at the same location, more research would need to be done in this area to understand this better.

Within this research, the effect of the different atmospheric conditions compared to the PM concentrations has been measured all over Vienna. The research did not look at the impacts of the meteorological condition on each measurement stations individually. The location of the measurement stations could have severely impacted the PM concentrations that were measured here. Within further research, it would be advised to take the location of the measurement stations into account when analysing the PM concentration data.

Another important discussion point of this research is the choice of the high PM concentration. The threshold concentration of 50 $\mu g \cdot m^{-3}$ for the PM10 concentrations and the 25 $\mu g \cdot m^{-3}$ for the PM2,5 concentrations was based on the threshold concentration data from the Austrian environmental agency (Umweltbundesamt, 2020). If the threshold concentrations from the WHO were chosen, this could have led to different outcomes within this research.

For the second part of this research, the measurements were made with the PM sensor on the bicycle in the Prater park. The mobile measurements were all taken with a self-made machine, made at the Institute of Meteorology and Climatology at BOKU. When looking at the data, there is some data missing in the data set of the second period of the measurements taken. An attempt was made to collect more data; this was not successful due to a malfunction in the machine. There is no reason that there was fewer missing data within the first measurement period. However, the path that is used contains rocks and potholes, and due to this movement, the PM sensor could have become damaged. However, when checked, no damage was found. The machine that was used to collect the data was untested and it was the first time that the machine was used. The machine would suddenly stop, potentially due to bad GPS signals or an

internal problem. As this was an experimental phase for the machine, technical issues would be expected. Thus, it would be recommended that the experiment should be repeated with an improved version of the PM sensor to reduce the number of technical failures of the machine.

Another important issue within the data collection period of this research is the global Coronavirus disease 2019 (COVID-19) pandemic that reached Austria in early 2020. Due to the outbreak of this pandemic the air pollutants emissions were changed. This was due to the countrywide lockdown that was decided in March 2020. This is an important aspect to consider when looking at the collected data, as the data was collected in March, in the early days of the lockdown and in May, when the lockdown was partially lifted. Although there is currently no research available for Vienna or the rest of Austria, as the pandemic is very recent, there are researches available for the United States and China that will be used as reference papers (Berman and Ebisu, 2020; Pei *et al.*, 2020; Wang *et al.*, 2020). Due to the reduction of travel by private car transport and the temporary reduction in large industries, certain pollutants were reduced, PM2,5 concentrations have been known to be reduced during lockdown periods (Berman and Ebisu, 2020; Wang *et al.*, 2020). However, high pollution events have not stopped occurring during the lockdown (Wang *et al.*, 2020). Due to these changes within the months of March and May 2020 that have occurred due to changes in anthropogenic behaviour, the PM concentrations that have been measured with the PM sensor could differ largely compared to other years. Thus, in order to assure that the data is correct, more measurements should be taken within the same measurement period within the next years in order to assure that the collected data is not impacted too much by the COVID-19 pandemic. The next part of the discussion will look at the outcome of the measurements made with the PM sensor.

Over the different measurement days a large difference was found in the PM concentrations. For this reason, the concentrations of the measured PM10 and PM2,5 concentrations show large differences in colours that indicate the PM concentrations in the maps, as can be found in Appendix G. The reasons for the large differences in PM concentrations during the different days could be due to the COVID-19 pandemic or due to machine malfunction. As has been discussed above, more research is necessary in this topic. When comparing the different locations, the results were as expected. The lowest PM10 and PM2,5 concentrations were found in the Prater park, at location number 1. Urban parks are well known for their properties of reducing the PM concentrations (Silli, Salvatori and Manes, 2015). Furthermore, there is little to no car activity in the park and no big factories and thus no large sources of PM. Thus, the results show that the lowest PM10 and PM2,5 concentrations can be found within the park. The highest PM10 concentrations are found on the highway A23, and there is no significant difference between the different roads when looking at the PM2,5 concentrations.

When looking at the impact of time of day on the measured PM concentrations, the results show that in almost all cases, the PM concentrations were higher during the second round of the day. The

measurements were taken early in the morning in order to assure that the PM concentrations were the highest and the temperature inversion could be measured (Flocas *et al.*, 2009). However, the results indicate that the PM concentrations are higher in the second round of measurements. This does not mean that there is no temperature inversion, the increase in the measured PM concentrations in the second round could be due to the increased traffic after the rush hour in Vienna (Palarz and Celiński-Mysław, 2017). In order to completely understand these results, it would be advised that mobile measurements are taken multiple rounds on a day, through the entire day. This could indicate if the PM concentrations are higher in the morning and if there is indeed a peak in the PM concentrations during the traffic rush hour.

The last aspect that needs to be discussed is the impact of the meteorological conditions on the mobile measurements. An important point that needs to be discussed here is the choice of the measurement day, this was dependent on the morning weather situation. The criteria for choosing a measurement day were that the day needed to be a weekday, no large precipitation events could occur the day before the measurements were taken or during the night before. This observation was made objectively, and this could have had an impact on the measurements that were taken. Due to the large amount of precipitation events within the second measurement period, there is a large difference between the measurement days.

When analysing the PM concentrations made with the PM sensor and the meteorological conditions on the different measurement days some of the found results were unexpected and need further explanation. The wind direction on both, the day with the lowest PM concentrations and the highest PM concentrations was north/east. Within the first part of this research it showed that this wind direction is mostly associated with low PM concentrations. However, when analysing the PM measured on the different days it showed that north/eastern winds also contributed to the highest PM concentrations. As the wind speed on the 17th of March, the day with the highest measured PM concentrations, was, in fact, the lowest measured wind speed, this could mean that the wind direction did not have a large impact on the PM concentration. Another explanation could be that the other metrological conditions play a larger role in the PM concentrations. More reach is necessary on this topic in order to understand if this occurrence is significant.

Although the analyzation of the wind speed on the PM10 and PM2,5 concentrations did not show significant results, this did show interesting results when looking at the PM concentrations made with the PM sensor. Both the highest PM10 and PM2,5 concentrations were found with the lowest measured wind speed on the 6 measurement days, and the lowest PM10 and PM2,5 concentrations were measured on the day with the highest measured wind speed. Wind speed did not show significant effects within the analyzation of the wind speed on the PM concentrations within this research. However, more research would be necessary on this part as the higher PM concentrations with lower wind speed and lower PM concentrations with higher wind speeds have been found within previous studies (Freutel *et*

al., 2013). However, as this phenomenon has only been found on two of the measurement days, it does not prove that this is a correct conclusion and as mentioned, more research is necessary.

When looking at the cyclonic or anticyclonic conditions at 925hPa and 500hPa and the PM concentrations measured with the PM sensor, the results show that in certain cases; with the highest PM10 concentrations and the cyclonic or anticyclonic conditions at 925hPa and 500hPa that the observations made were correct. However, this was only the case for the observation made at 925hPa and the lower measured PM10 concentrations with the PM sensor. For the PM2,5 concentrations, no conclusions could be made between the PM concentrations measured with the PM sensor and the meteorological conditions as the cyclonic or anticyclonic conditions at 925hPa and 500hPa did not show significant results.

The comparison of the humidity conditions to the PM10 and PM2,5 concentrations measured on the different measurement days using the PM sensor showed the best results. In all cases, the humidity conditions matched the day with the highest measured PM10 and PM2,5 concentrations.

The days on which the measurements were taken were specifically chosen because there was none or little precipitation in the days leading up to the day that the measurements were taken. Furthermore, the first part of the research showed that precipitation did not have a significant effect on the PM concentrations. Due to the fact that none of the measurement days had precipitation, this could not be analyzed in further detail, and no new observations could be made. It would be advised that within further research, the days are picked at random and precipitation could also be analyzed within the results.

Within further research, it would be advised that more days would be analyzed in order to be able to get more results on the impact of the meteorological conditions. Furthermore, it is advised that the meteorological conditions are compared at a more local level, unlike within this research, where the data was an average of all of Vienna.

5. Conclusion

When looking at the PM10 concentrations, the results show that wind direction, cyclonic or anticyclonic conditions at 925hPa and at 500hPa and humidity conditions have a significant impact on the PM10 concentrations. With eastern, south/eastern and southern winds, cyclonic conditions at 925hPa, anticyclonic conditions at 500hPa and wet humidity conditions cause the highest PM10 concentrations. When looking at the high PM10 concentrations above the threshold, only dry humidity conditions caused significantly higher PM10 concentrations. When looking at the PM2,5 concentrations the results show that only wind direction and humidity conditions have a significant impact on the concentrations. With eastern, south/eastern and southern winds and wet humidity conditions cause the highest PM2,5 concentrations. When looking at the above the threshold PM2,5 concentrations, anticyclonic conditions at 925hPa and dry humidity conditions showed significantly higher PM2,5 concentrations. The first hypothesis that states *that the measured meteorological conditions (wind direction, cyclonic and anticyclonic conditions at 925hPa and 500hPa and humidity) will have a significant impact on the PM10 and PM2,5 concentrations* is only partly correct. As this research shows that not all the meteorological conditions have the same significant impact on the PM10 and PM2,5 concentrations.

When looking at the mobile measurements, the lowest PM10 and PM2,5 concentration levels were found in Prater park. The highest PM10 concentrations were measured beside the A23 highway. For the PM2,5 concentrations no significant difference was found between measurements beside the highway and on the roads. Overall, the highest PM concentrations were measured in the second round of the day. When analysing the PM10 and PM2,5 concentrations with the meteorological conditions the results show that the measured meteorological conditions that were found to have a significant effect on the PM10 and PM2,5 concentrations only rarely impact the concentrations as expected. The second hypothesis states that *the spatial distribution and with this, the surrounding characteristics of a location have a significant effect on the PM10 and PM2,5 concentrations and will impact the measured concentrations significantly* has shown to be correct.

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7. Appendix

A. Appendix

In order to analyse the significant differences between the PM concentrations measured at the different stations, it is necessary to know if the data that was collected at each measurement station is normally distributed or not normally distributed (parametric or non-parametric). As there is a large variation in the PM concentrations due to the different season and their associated higher and lower PM concentrations, it could be expected that the PM10 and PM2,5 concentrations will not be normally distributed. The Kolmogorov-Smirnov test will be performed to test this, the output for the test has been shown in Appendix Table 1. All the data that was collected by each measurement station through the measurement period was analysed.

Appendix Table 1: One-Sample Kolmogorov-Smirnov Test to test to analyse if the data at the different measurement stations is normally distributed.

Station name	N	Normal Parametersa,b		Most Extreme Differences			Test Statistic	Asymp. Sig. (2-tailed)
		Mean	Std. Deviation	Absolute	Positive	Negative		
PM10 AT900KE	3426	26,42101	16,85107	0,129	0,129	-0,103	0,129	0,000 c
PM10 AT90AKC	4884	24,93539	16,59711	0,134	0,134	-0,109	0,134	0,000 c
PM10 AT90FLO	3283	27,28828	17,93837	0,142	0,142	-0,114	0,142	0,000 c
PM10 AT90LAA	3271	25,51551	17,10747	0,138	0,138	-0,118	0,138	0,000 c
PM10 AT90LOB	3257	22,25629	14,42995	0,149	0,149	-0,122	0,149	0,000 c
PM10 AT90TAB	4394	28,78293	19,08377	0,127	0,127	-0,107	0,127	0,000 c
PM10 AT9BELG	4908	27,56547	18,69453	0,129	0,129	-0,109	0,129	0,000 c
PM10 AT9GAUD	4711	25,82975	17,20466	0,136	0,136	-0,109	0,136	0,000 c
PM10 AT9KEND	4537	25,99797	16,86581	0,13	0,13	-0,106	0,13	0,000 c
PM10 AT9LIES	5432	28,57055	19,12818	0,124	0,124	-0,1	0,124	0,000 c
PM10 AT9RINN	3927	33,42776	20,78287	0,136	0,136	-0,109	0,136	0,000 c
PM10 AT9SCHA	4009	22,96266	16,23637	0,137	0,137	-0,125	0,137	0,000 c
PM10 AT9STAD	3985	28,6719	18,89985	0,138	0,138	-0,113	0,138	0,000 c
Average PM10 concentration in $\mu g \cdot m^{-3}$	5992	26,6478	16,70734	0,125	0,125	-0,099	0,125	0,000 c
PM2,5 AT90AKC	4855	18,54811	13,94337	0,157	0,157	-0,131	0,157	0,000 c
PM2,5 AT90LOB	2348	14,06228	12,10447	0,179	0,179	-0,153	0,179	0,000 c
PM2,5 AT90TAB	3714	18,98223	13,76867	0,149	0,149	-0,124	0,149	0,000 c
PM2,5 AT9KEND	1094	18,11592	13,72082	0,155	0,155	-0,134	0,155	0,000 c
PM2,5 AT9RINN	1025	19,89465	15,17541	0,161	0,161	-0,142	0,161	0,000 c
PM2,5 AT9STAD	1084	19,0365	14,60287	0,16	0,16	-0,139	0,16	0,000 c

Average PM2,5 concentration in $\mu g \cdot m^{-3}$	4876	18,8045	13,933	0,148	0,148	-0,126	0,148	0,000 [c]

[a] Test distribution is Normal.

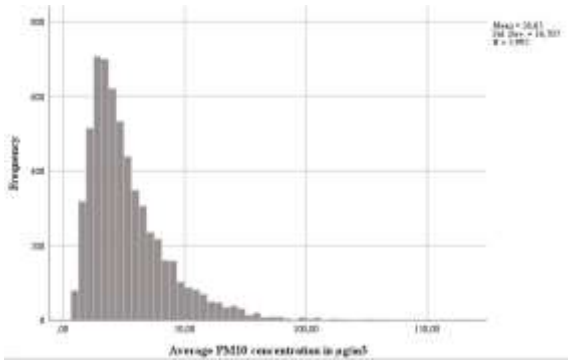
[b] Calculated from data.

[c] Lilliefors Significance correction.

In Appendix Table 1, the PM concentrations at the measurement stations have been tested for normal distribution. The output shows that the data is significant ($p<0,05$), thus it can be assumed that the data is non-parametric. This will affect the tests that will be used in order to analyse the data within the research. Two extra values have been added within this table, PM10 Average and PM2,5 Average these are both the average PM10 concentrations of all measurement stations combined and the average PM2,5 concentrations of all the measurement stations.

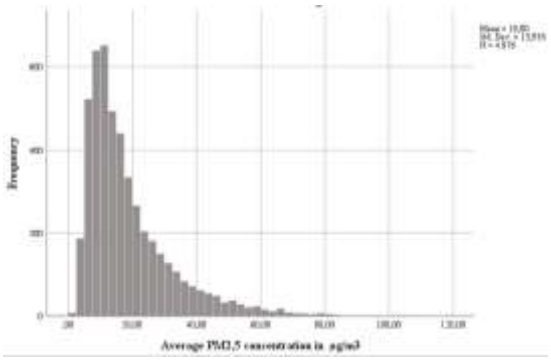
In order to show a visual representation of the distribution of the PM data, the average PM2,5 concentrations and the average PM10 concentrations have been depicted in histograms within Appendix figure 1.

Histogram of PM10 concentrations



Appendix figure 1A: histogram of the PM10 concentrations.

Histogram of PM2,5 concentrations



Appendix figure 1B: histogram of the PM10 concentrations

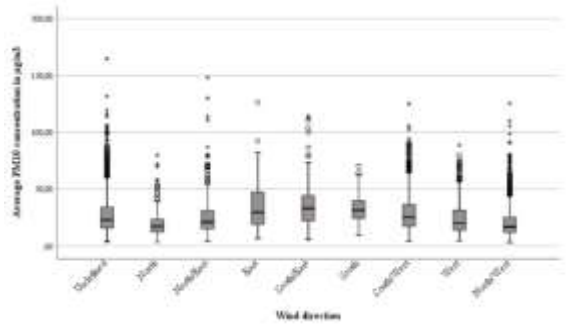
Appendix figure 1: histograms of PM10 and PM2,5 concentrations collected during the measurement period.

As can be seen in Appendix figure 1A and B all the data is positively skewed according to the One-Sample Kolmogorov-Smirnov in Appendix Table 1 the data is not normally distributed.

B. Appendix

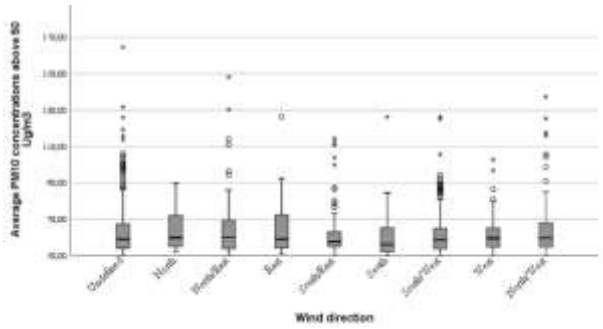
In order to analyse the distribution of the PM concentration and the wind direction in further detail, boxplots have been made to get a better overview of the distribution of the PM concentration under the different wind directions.

Boxplot showing the wind direction and the assosiated PM10 concentrations



Appendix figure 2A: PM10 concentrations and wind directions.

Boxplot showing the wind direction and the assosiated PM10 concentrations that were mesured above the theshold



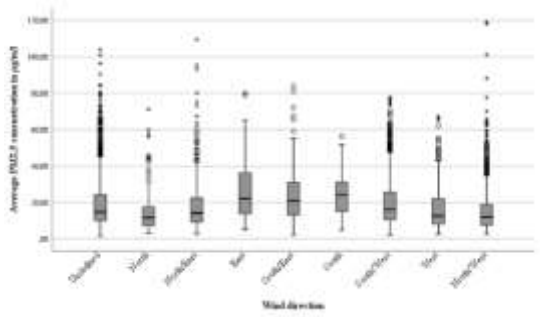
Appendix figure 2B: PM10 concentrations mesured above the 50µg·m^{-3} threshold and wind directions.

Appendix figure 2: Boxplots of the PM10 concentrations, all the PM10 concentrations and the PM10 concentrations above the threshold.

Appendix figure 2A, shows a boxplot of the different wind directions and the distribution of the average PM10 concentration for all the measurement stations combined. When looking at the highest value measured, this belongs to an outlier that belongs to the undefined wind directions. However, when looking at the median PM10 concentrations the wind direction east, south/east, and south shows the highest concentration values and northern wind shows the lowest.

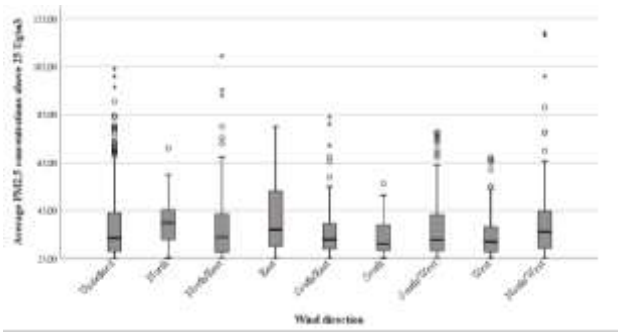
Appendix figure 2B, shows the boxplot of the PM10 concentrations that are above the 50 µg·m^{-3} threshold for all the different wind directions. All the PM10 concentrations that are below 50 µg·m^{-3} are not considered within the analysis. In the figure it can be seen that there is still a large distribution within the PM10 concentrations at all the different wind speeds. This is similar to the boxplot of all the PM10 concentrations in Appendix figure 2A.

Boxplot showing the wind direction and the assosiated PM2,5 concentrations



Appendix figure 3A: PM2,5 concentrations and wind directions.

Boxplot showing the wind direction and the assosiated PM2,5 concentrations that were mesured above the theshold



Appendix figure 3*B: PM2,5 concentrations mesured above the 25µg·m^{-3} threshold and wind directions.*

Appendix figure 3: Boxplots of the PM2,5 concentrations, all the PM2,5 concentrations and the PM10 concentrations above the threshold.

Appendix figure 3A shows that there are some differences in the distribution of the PM2,5 concentrations. The highest PM2,5 concentration is found with north/western winds, this is however an outlier. The higher median concentration can be found with an eastern wind. There is a large amount of variation between the measured PM2,5 concentrations. The boxplot does not show the significant differences between the stations.

Appendix figure 3B depicts the boxplot of the average PM2,5 concentrations that were measured above the 25 µg/m^3 threshold. Here it can be seen that there is a lot of variation within the measured concentrations. The highest concentration that was measured was measured with north/western winds, however this seems to be an outlier. The highest median concentration is found with northern winds. The largest number of outliers is found with the undefined wind direction.

Below, the PM concentrations from each different wind direction are compared to each other. This will be done in order to test if certain wind directions lead to higher PM concentrations. As the PM concentrations is normally distributed (as shown in appendix A), the Mann-Whitney U test will be used to analyse the data.

The Mann-Whitney U test can only fully be used when looking at the mean ranks. Appendix Table 1 shows the entire output for the Mann-Whitney U test when comparing the PM10 concentrations at different wind directions.

Appendix Table 2: All the output for the Mann-Whitney U test, with the mean rank and the sum of rank. For PM10 concentrations at all the different observed wind directions.

Wind direction	*N*	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
Undefined	1931	1079,50 [b]	2084518,50			
North	176	774,20	136259,50			
	2107			120683,500	-6,373	0,000 [a]
Undefined	1931	1206,29 [b]	2329339,00			
North/east	447	1116,98	499292,00			
	2378			399164,000	-2,478	0,013 [a]
Undefined	1931	994,89	1921134,50			
East	76	1235,44 [b]	93893,50			
	2007			55788,500	-3,549	0,000 [a]
Undefined	1931	1033,93	1996519,00			
South/east	196	1360,25 [b]	266609,00			
	2127			131173,000	-7,088	0,000 [a]
Undefined	1931	993,86	1919149,50			
South	82	1316,36 [b]	107941,50			
	2013			53803,500	-4,921	0,000 [a]
Undefined	1931	1666,13	3217303,50			
South/west	1514	1795,53 [b]	2718431,50			

	3445			1351957,500	-3,790	0,000 [a]
Undefined	1931	1288,28 [b]	2487671,50			
West	577	1141,45	658614,50			
	2508			491861,500	-4,274	0,000 [a]
Undefined	1931	1601,15 [b]	3091818,00			
North/west	993	1192,88	1184532,00			
	2924			691011,000	-12,384	0,000 [a]
North	176	262,54	46207,50			
North/east	447	331,47 [b]	148168,50			
	623			30631,500	-4,304	0,000 [a]
North	176	107,97	19002,00			
East	76	169,42 [b]	12876,00			
	252			3426,000	-6,143	0,000 [a]
North	176	131,42	23130,00			
South/east	196	235,96 [b]	46248,00			
	372			7554,000	-9,362	0,000 [a]
North	176	104,35	18366,00			
South	82	183,48 [b]	15045,00			
	258			2790,000	-7,930	0,000 [a]
North	176	568,29	100019,50			
South/west	1514	877,72 [b]	1328875,50			
	1690			84443,500	-7,962	0,000 [a]
North	176	329,92	58066,00			
West	577	391,36 [b]	225815,00			
	753			42490,000	-3,280	0,001 [a]
North	176	590,09 [b]	103855,50			
North/west	993	584,10	580009,50			
	1169			86488,500	-0,217	0,828
North/east	447	250,51	111978,00			
East	76	329,58 [b]	25048,00			
	523			11850,000	-4,217	0,000 [a]
North/east	447	285,36	127555,00			
South/east	196	405,57 [b]	79491,00			
	643			27427,000	-7,554	0,000 [a]
North/east	447	248,56	111108,00			
South	82	354,60 [b]	29077,00			
	529			10980,000	-5,774	0,000 [a]
North/east	447	866,62	387379,00			
South/west	1514	1014,77 [b]	1536362,00			
	1961			287251,000	-4,861	0,000 [a]
North/east	447	526,34 [b]	235272,50			
West	577	501,78	289527,50			
	1024			122774,500	-1,318	0,188
North/east	447	827,24 [b]	369778,50			
North/west	993	672,45	667741,50			

	1440			174220,500	-6,536	0,000 [a]
East	76	133,18	10122,00			
South/east	196	137,79 [b]	27006,00			
	272			7196,000	-,433	0,665
East	76	79,18	6018,00			
South	82	79,79 [b]	6543,00			
	158			3092,000	-,084	0,933
East	76	930,07 [b]	70685,00			
South/west	1514	788,75	1194160,00			
	1590			47305,000	-2,618	0,009 [a]
East	76	424,49 [b]	32261,50			
West	577	314,16	181269,50			
	653			14516,500	-4,793	0,000 [a]
East	76	768,16 [b]	58380,00			
North/west	993	517,16	513535,00			
	1069			20014,000	-6,831	0,000 [a]
South/east	196	141,11 [b]	27658,50			
South	82	135,64	11122,50			
	278			7719,500	-,518	0,605
South/east	196	1038,12 [b]	203472,00			
South/west	1514	831,86	1259433,00			
	1710			112578,000	-5,503	0,000 [a]
South/east	196	503,33 [b]	98653,00			
West	577	347,48	200498,00			
	773			33745,000	-8,442	0,000 [a]
South/east	196	861,69 [b]	168891,50			
North/west	993	542,36	538563,50			
	1189			45042,500	-11,898	0,000 [a]
South	82	981,95 [b]	80519,50			
South/west	1514	788,56	1193886,50			
	1596			47031,500	-3,701	0,000 [a]
South	82	451,62 [b]	37032,50			
West	577	312,72	180437,50			
	659			13684,500	-6,182	0,000 [a]
South	82	822,41 [b]	67437,50			
North/west	993	514,51	510912,50			
	1075			17391,500	-8,631	0,000 [a]
South/west	1514	1101,06 [b]	1666998,50			
West	577	901,54	520187,50			
	2091			353434,500	-6,754	0,000 [a]
South/west	1514	1427,97 [b]	2161953,50			
North/west	993	988,75	981824,50			
	2507			488303,500	-14,859	0,000 [a]
West	577	866,82 [b]	500155,50			
North/west	993	738,25	733079,50			

	1570		239558,500	-5,418	0,000 [a]

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

Appendix Table 3 shows an overview of Appendix Table 2, here all the values are removed and the table only looks at which wind direction causes the significantly higher PM10 concentrations.

Appendix Table 3: Summary overview of the output of the Mann-Witney U test as displayed in Appendix Table 2.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	U								
North/East	U	N/E							
East	E	E	E						
South/East	S/E	S/E	S/E	-					
South	S	S	S	-	-				
South/West	S/W	S/W	S/W	E	S/E	S			
West	U	W	-	E	S/E	S	S/W		
North/West	U	-	N/E	E	S/E	S	S/W	W	

Both Appendix Table 2 and Appendix Table 3 show that in most cases there is a significant difference between the PM10 concentrations and the different wind directions. Appendix Table 2 gives a clear overview of which wind direction leads to the highest PM10 concentrations.

The output for the Mann-Whitney U test for the PM10 concentrations that have been measured above the 50 $\mu g \cdot m^{-3}$ threshold showed that all the values had no significant difference. Therefore, the entire output of the Mann-Whitney U test will not be shown.

Appendix Table 4 shows the entire output for the Mann-Whitney U test when comparing the PM2,5 concentrations at different wind directions.

Appendix Table 4: All the output for the Mann-Whitney U test, with the mean rank and the sum of rank. For PM2,5 concentrations at all the different observed wind directions.

Wind direction	*N*	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
Undefined	1598	883,34 [b]	1411576,00			
North	136	681,39	92669,00			
	1734			83353,000	-4,515	0,000 [a]
Undefined	1598	989,81 [b]	1581715,00			
North/east	360	933,74	336146,00			
	1958			271166,000	-1,700	0,089

Undefined	1598	821,87	1313350,50			
East	63	1062,55 [b]	66940,50			
	1661			35749,500	-3,907	0,000 [a]
Undefined	1598	858,25	1371488,50			
South/east	159	1087,51 [b]	172914,50			
	1757			93887,500	-5,434	0,000 [a]
Undefined	1598	816,62	1304953,00			
South	53	1108,92 [b]	58773,00			
	1651			27352,000	-4,392	0,000 [a]
Undefined	1598	1396,84	2232148,50			
South/west	1260	1470,92 [b]	1853362,50			
	2858			954547,500	-2,383	0,017 [a]
Undefined	1598	1058,25 [b]	1691080,50			
West	459	927,17	425572,50			
	2057			320002,500	-4,167	0,000 [a]
Undefined	1598	1271,02 [b]	2031084,00			
North/west	788	1036,30	816607,00			
	2386			505741,000	-7,827	0,000 [a]
North	136	217,17	29534,50			
North/east	360	260,34 [b]	93721,50			
	496			20218,500	-2,993	0,003 [a]
North	136	84,83	11537,00			
East	63	132,75 [b]	8363,00			
	199			2221,000	-5,460	0,000 [a]
North	136	110,59	15040,00			
South/east	159	180,00 [b]	28620,00			
	295			5724,000	-6,967	0,000 [a]
North	136	80,24	10912,50			
South	53	132,88 [b]	7042,50			
	189			1596,500	-5,943	0,000 [a]
North	136	519,50	70652,00			
South/west	1260	717,82 [b]	904454,00			
	1396			61336,000	-5,451	0,000 [a]
North	136	274,38	37315,00			
West	459	305,00 [b]	139995,00			
	595			27999,000	-1,825	0,068
North	136	449,10	61078,00			
North/west	788	464,81 [b]	366272,00			
	924			51762,000	-0,634	0,526
North/east	360	201,44	72518,50			
East	63	272,34 [b]	17157,50			
	423			7538,500	-4,247	0,000 [a]
North/east	360	235,34	84722,50			
South/east	159	315,83 [b]	50217,50			
	519			19742,500	-5,637	0,000 [a]

North/east	360	196,28	70662,50			
South	53	279,78 [b]	14828,50			
	413			5682,500	-4,755	0,000 [a]
North/east	360	741,74	267025,00			
South/west	1260	830,15 [b]	1045985,00			
	1620			202045,000	-3,163	0,002 [a]
North/east	360	425,50 [b]	153180,00			
West	459	397,84	182610,00			
	819			77040,000	-1,661	0,097
North/east	360	628,97 [b]	226428,00			
North/west	788	549,62	433098,00			
	1148			122232,000	-3,762	0,000 [a]
East	63	116,26 [b]	7324,50			
South/east	159	109,61	17428,50			
	222			4708,500	-0,695	0,487
East	63	57,81	3642,00			
South	53	59,32 [b]	3144,00			
	116			1626,000	-0,241	0,809
East	63	819,56 [b]	51632,50			
South/west	1260	654,12	824193,50			
	1323			29763,500	-3,354	0,001 [a]
East	63	351,64 [b]	22153,50			
West	459	249,13	114349,50			
	522			8779,500	-5,059	0,000 [a]
East	63	603,29 [b]	38007,00			
North/west	788	411,83	324519,00			
	851			13653,000	-5,949	0,000 [a]
South/east	159	103,90	16520,00			
South	53	114,30 [b]	6058,00			
	212			3800,000	-1,069	0,285
South/east	159	845,08 [b]	134367,00			
South/west	1260	692,95	873123,00			
	1419			78693,000	-4,411	0,000 [a]
South/east	159	393,85 [b]	62621,50			
West	459	280,28	128649,50			
	618			23079,500	-6,912	0,000 [a]
South/east	159	644,61 [b]	102493,00			
North/west	788	439,57	346385,00			
	947			35519,000	-8,623	0,000 [a]
South	53	852,31 [b]	45172,50			
South/west	1260	648,78	817468,50			
	1313			23038,500	-3,828	0,000 [a]
South	53	360,48 [b]	19105,50			
West	459	244,49	112222,50			
	512			6652,500	-5,404	0,000 [a]

South	53	625,50 [b]	33151,50			
North/west	788	407,25	320909,50			
	841			10043,500	-6,332	0,000 [a]
South/west	1260	900,50 [b]	1134635,50			
West	459	748,81	343704,50			
	1719			238134,500	-5,606	0,000 [a]
South/west	1260	1121,89 [b]	1413576,50			
North/west	788	868,78	684599,50			
	2048			373733,500	-9,424	0,000 [a]
West	459	651,37 [b]	298981,00			
North/west	788	608,05	479147,00			
	1247			168281,000	-2,049	0,040 [a]

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

Appendix table 5 shows an overview of Appendix Table 4, here all the values are removed and the table only looks at which wind direction causes the significantly higher PM2,5 concentrations.

Appendix table 5: Summary overview of the output of the Mann-Witney U test as displayed in Appendix Table 4.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	U								
North/East	-	N/E							
East	E	E	E						
South/East	S/E	S/E	S/E	-					
South	S	S	S	-	-				
South/West	S/W	S/W	S/W	E	S/E	S			
West	U	-	W	E	S/E	S	S/W		
North/West	U	-	N/W	E	S/E	S	S/W	W	

Most of the PM2,5 concentrations did not have significant differences. However due to the fact that there were some significant differences found between certain wind directions, the output of the Mann-Whitney U test will be shown in order to analyse which wind direction causes the highest average PM2,5 concentrations above the threshold. The output is show in Appendix table 6.

Appendix table 6: The output for the Mann-Whitney U test, with the mean rank and the sum of rank. For PM2,5 concentrations that have been measured above the 25$\mu g \cdot m^{-3}$ at all the different observed wind directions.

Wind direction	*N*	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
Undefined	442	228,14	100837,50			

North	18	288,47 [b]	5192,50			
	460			2934,500	-1,888	0,059
Undefined	442	263,36	116407,00			
North/east	85	267,31 [b]	22721,00			
	527			18504,000	-0,219	0,827
Undefined	442	233,86	103366,00			
East	30	275,40 [b]	8262,00			
	472			5463,000	-1,614	0,106
Undefined	442	255,39	112881,50			
South/east	70	263,52 [b]	18446,50			
	512			14978,500	-0,427	0,669
Undefined	442	237,37 [b]	104919,00			
South	29	215,07	6237,00			
	471			5802,000	-0,855	0,393
Undefined	442	416,24 [b]	183978,00			
South/west	382	408,17	155922,00			
	824			82769,000	-0,485	0,628
Undefined	442	284,88 [b]	125917,50			
West	113	251,08	28372,50			
	555			21931,500	-2,000	0,046 [a]
Undefined	442	285,06	125995,00			
North/west	138	307,93 [b]	42495,00			
	580			28092,000	-1,400	0,161
North	18	61,47 [b]	1106,50			
North/east	85	49,99	4249,50			
	103			594,500	-1,481	0,139
North	18	25,33 [b]	456,00			
East	30	24,00	720,00			
	48			255,000	-,319	0,749
North	18	54,42 [b]	979,50			
South/east	70	41,95	2936,50			
	88			451,500	-1,847	0,065
North	18	29,97 [b]	539,50			
South	29	20,29	588,50			
	47			153,500	-2,353	0,019 [a]
North	18	256,78 [b]	4622,00			
South/west	382	197,85	75578,00			
	400			2425,000	-2,114	0,035 [a]
North	18	89,81 [b]	1616,50			
West	113	62,21	7029,50			
	131			588,500	-2,865	0,004 [a]
North	18	90,69 [b]	1632,50			
North/west	138	76,91	10613,50			
	156			1022,500	-1,218	0,223
North/east	85	55,84	4746,00			

East	30	64,13 [b]	1924,00			
	115			1091,000	-1,172	0,241
North/east	85	77,76	6609,50			
South/east	70	78,29 [b]	5480,50			
	155			2954,500	-0,074	0,941
North/east	85	59,10 [b]	5023,50			
South	29	52,81	1531,50			
	114			1096,500	-0,885	0,376
North/east	85	240,44 [b]	20437,50			
South/west	382	232,57	88840,50			
	467			15687,500	-0,487	0,627
North/east	85	106,77 [b]	9075,50			
West	113	94,03	10625,50			
	198			4184,500	-1,549	0,121
North/east	85	108,11	9189,50			
North/west	138	114,39 [b]	15786,50			
	223			5534,500	-0,706	0,480
East	30	56,18 [b]	1685,50			
South/east	70	48,06	3364,50			
	100			879,500	-1,283	0,200
East	30	34,12 [b]	1023,50			
South	29	25,74	746,50			
	59			311,500	-1,873	0,061
East	30	245,72 [b]	7371,50			
South/west	382	203,42	77706,50			
	412			4553,500	-1,874	,0061
East	30	89,45 [b]	2683,50			
West	113	67,37	7612,50			
	143			1171,500	-2,596	0,009 [a]
East	30	90,95 [b]	2728,50			
North/west	138	83,10	11467,50			
	168			1876,500	-0,801	0,423
South/east	70	51,90 [b]	3633,00			
South	29	45,41	1317,00			
	99			882,000	-1,023	0,306
South/east	70	236,22 [b]	16535,50			
South/west	382	224,72	85842,50			
	452			12689,500	-0,677	0,498
South/east	70	101,09 [b]	7076,50			
West	113	86,37	9759,50			
	183			3318,500	-1,828	0,068
South/east	70	99,96	6997,50			
North/west	138	106,80 [b]	14738,50			
	208			4512,500	-0,774	0,439
South	29	191,17	5544,00			

South/west	382	207,13 [b]	79122,00			
	411			5109,000	-0,0697	0,486
South	29	73,05 [b]	2118,50			
West	113	71,10	8034,50			
	142			1593,500	-0,228	0,820
South	29	71,05	2060,50			
North/west	138	86,72 [b]	11967,50			
	167			1625,500	-1,587	0,113
South/west	382	253,81 [b]	96956,50			
West	113	228,35	25803,50			
	495			19362,500	-1,663	0,096
South/west	382	253,41	96803,50			
North/west	138	280,12 [b]	38656,50			
	520			23650,500	-1,790	0,073
West	113	111,75	12628,00			
North/west	138	137,67 [b]	18998,00			
	251			6187,000	-2,814	0,005 [a]

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

Appendix table 7 shows a summarized version of Appendix table 6, showing only the wind directions that display significant differences in PM2,5 concentrations from each other.

Appendix table 7: Summary overview of the output of the Mann-Witney U test as displayed in Appendix table 6.

	Undefined	*North*	*North/East*	*East*	*South/East*	*South*	*South/West*	*West*	*North/West*
Undefined									
North	-								
North/East	-	-							
East	-	-	-						
South/East	-	-	-	-					
South	-	N	-	-	-				
South/West	-	N	-	-	-	-			
West	U	N	-	-	-	-	-		
North/West	-	-	-	-	-	-	-	N/W	

C. Appendix

The Kolmogorov-Smirnov test has been performed in order to test if the wind speed data is normally distributed. As there is a large amount of data, spread out over many years it could be expected that the wind speed data will not be normally distributed. Appendix table 8 shows the output from the One-sample Kolmogorov-Smirnov test for the wind speed.

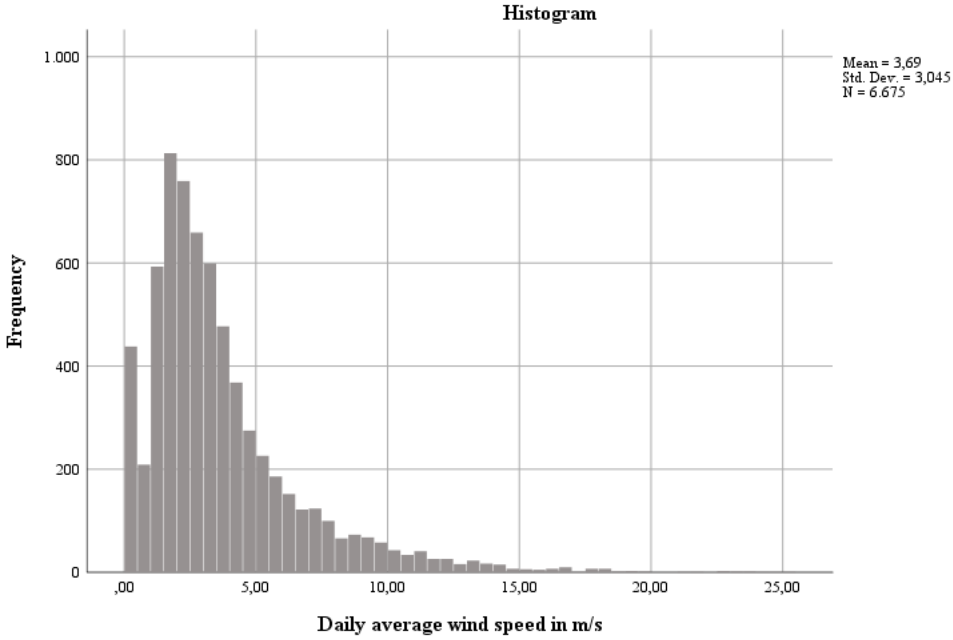
Appendix table 8: Output for the One-Sample Kolmogorov-Smirnov Test to test to analyse if the data of the daily average wind speed is normally distributed.

	N	Normal Parametersa,b		Most Extreme Differences			Test Statistic	Asymp. Sig. (2-tailed)
		Mean	Std. Deviation	Absolute	Positive	Negative		
Daily average wind speed in m/s	6949	3,7006	3,09162	0,139	0,139	-0,116	0,139	,000[c]

[a] Test distribution is Normal.

[c] Lilliefors Significance correction.

Appendix table 8 shows that the daily average wind speed is not normally distributed ($p<0,05$). Thus, the Spearman's rho test will be used in order to analyse the correlation between the PM concentrations and the wind speed as both test variables are not normally distributed. Appendix figure 4 shows the histogram of the distribution of the wind speed. This histogram shows what has been proven with the One-sample Kolmogorov-Smirnov test, that the wind speed data is not normally distributed, and that the data is positively skewed.



Appendix figure 4: Histogram of the daily average wind speed.

D. Appendix

Below the output for the Mann-Whitney U test has been shown for the PM concentrations under the cyclonic or anticyclonic conditions at 925hPa and 500hPa.

Appendix table 9:Output for the Mann-Whitney U test for the PM10 concentrations at different cyclonic or anticyclonic conditions.

		N	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
PM10 concentrations at 925hPa	Cylonic	2820	3145,03 [b]	8868970,50			
	Anticyclonic	3172	2864,46	9086057,50			
		5992			4053679,500	-6,267	0,000 [a]
PM10 concentrations above the 50 µg·m^{-3} threshold at 925hPa	Cylonic	524	590,68 [b]	309518,50			
	Anticyclonic	656	590,35	387271,50			
		1180			171775,500	-0,017	0,987
PM10 concentraties at 500hPa	Cylonic	2202	2870,08	6319912,50			
	Anticyclonic	3790	3069,95 [b]	11635115,50			
		5992			3894409,500	-4,312	0,000 [a]
PM10 concentrations above the 50 µg·m^{-3} threshold at 500hPa	Cylonic	401	602,02 [b]	241411,00			
	Anticyclonic	779	584,57	455379,00			
		1180			151569,000	-0,833	0,405

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

Appendix table 9 shows the output for the Mann-Whitney U test for the PM10 concentrations at the different cyclonic or anticyclonic conditions. Appendix table 10 shows the output for the Mann-Whitney U test for the PM2,5 concentrations at the different cyclonic or anticyclonic conditions.

Appendix table 10: Output for the Mann-Whitney U test for the PM10 concentrations at different cyclonic or anticyclonic conditions.

		N	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
PM2,5 concentrations at 925hPa	Cylonic	2307	2466,50 [b]	5690206,50			
	Anticyclonic	2569	2413,36	6199919,50			
		4876			2898754,500	-1,316	0,188
PM2,5 concentrations	Cylonic	557	622,22	346575,50			
	Anticyclonic	750	677,60 [b]	508202,50			

above the 25 µg·m^{-3} threshold at 925hPa		1307			191172,500	-2,624	0,009 [a]
PM2,5 concentrations at 500hPa	Cylonic	1774	2423,25	4298841,50			
	Anticyclonic	3102	2447,22 [b]	7591284,50			
		4876			2724416,500	-0,572	0,567
PM2,5 concentrations above the 25 µg·m^{-3} threshold at 500hPa	Cylonic	481	668,51 [b]	321551,50			
	Anticyclonic	826	645,55	533226,50			
		1307			191675,500	-1,060	0,289

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

E. Appendix

In Appendix table 11 the output for the humidity conditions, defined into wet and dry tested with the Mann-Whitney U test.

Appendix table 11: Output for the Mann-Whitney U test looking at the wet and dry humidity conditions.

		N	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
PM10 concentraions	Wet	3208	3206,51 [b]	10286498,50			
	Dry	2784	2754,50	7668529,50			
		5992			3791809,500	-10,088	0,000 [a]
PM10 concentrations above the 50µg·m^{-3} threshold	Wet	640	565,57	361963,50			
	Dry	540	620,05 [b]	334826,50			
		1180			156843,500	-2,736	0,006 [a]
PM2,5 concentraions	Wet	2649	2565,49 [b]	6795981,00			
	Dry	2227	2287,45	5094145,00			
		4876			2613267,000	-6,870	0,000 [a]
PM2,5concentrations above the 25µg·m^{-3} threshold	Wet	737	613,62	452239,50			
	Dry	570	706,21 [b]	402538,50			
		1307			180286,500	-4,398	0,000 [a]

[a] Significant difference are displayed at p=0,05 level

[b] Highest of the measured mean ranks

F. Appendix

The One-sample Kolmogorov-Smirnov test has been used to test if the daily precipitation data is normal distributed or not. Appendix table 12 shows the output for the one-Sample Kolmogorov-Smirnov Test.

Appendix table 12: Output for the One-Sample Kolmogorov-Smirnov Test to test if the data of the daily average precipitation is normally distributed.

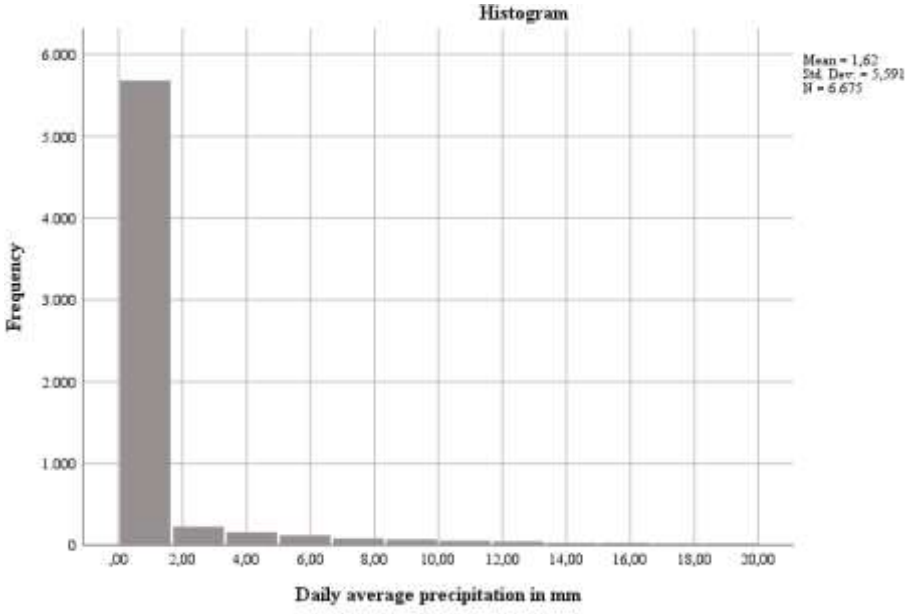
	N	Normal Parameters b		Most Extreme Differences			Test Statistic	Asymp. Sig. (2-tailed)
		Mean	Std. Deviation	Absolute	Positive	Negative		
Daily average precipitation in mm	6675	1,6219	5,59087	0,386	0,379	-0,386	0,386	0,000 [c]

[a] Test distribution is Normal.

[b] Calculated from data.

[c] Lilliefors Significance correction.

As shown in Appendix table 12 the precipitation data is not normally distributed ($p<0,05$). Appendix figure 5 gives a visual representation of the precipitation data. The figure shows that the precipitation data is positively skewed.



Appendix figure 5: Histogram of the daily average precipitation.

G. Appendix

One sample Kolmogorov-Smirnoff test for PM10 and PM2,5 data for the data collected with the PM sensor is o test if the data is normally distributed or not.

Appendix table 13: Output for the One-Sample Kolmogorov-Smirnov Test to if the PM data collected with the PM sensor is normally distributed.

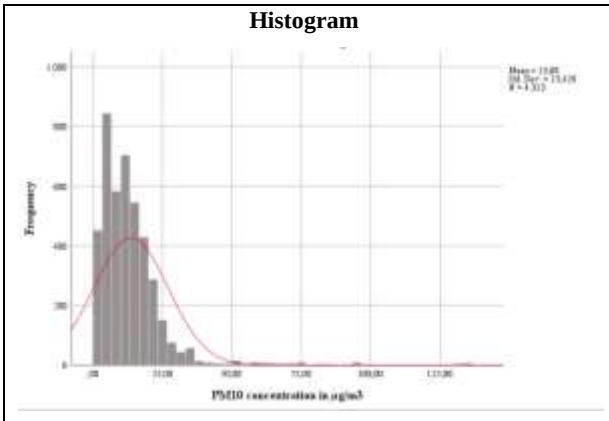
	N	Normal Parametersa,b		Most Extreme Differences			Test Statistic	Asymp. Sig. (2-tailed)
		Mean	Std. Deviation	Absolute	Positive	Negative		
PM10 concentration in µg/m3	4313	13,6824	13,42565	0,16	0,15	-0,16	0,16	,000 c
PM2,5 concentration in µg/m3	4313	4,4997	3,08427	0,094	0,094	-0,086	0,094	,000 c

[a] Test distribution is Normal.

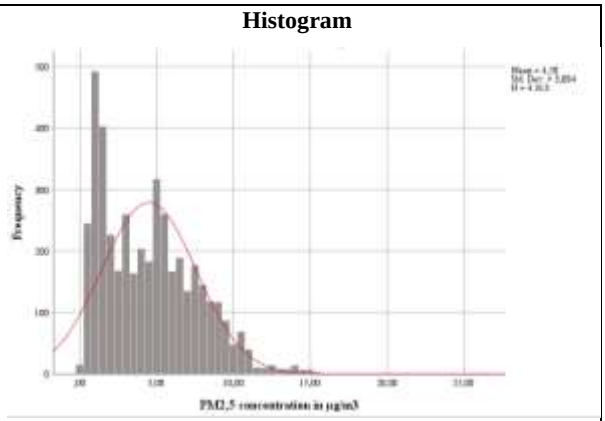
[b] Calculated from data.

[c] Lilliefors Significance correction.

Appendix table 12 shows that the data is not normally distributed ($p<0,05$). Appendix figure 6 shows the visual representation of the PM concentrations as they were measured during the measurement period with the PM sensor. The figure shows that the PM concentration positively skewed. The figure also shows that there is a significant difference between the distribution of the PM10 and PM2,5 concentrations.



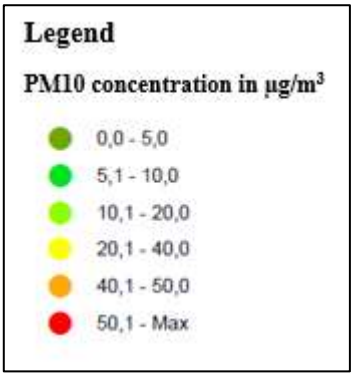
Appendix table 6A: Histogram of the PM10 concentrations.



Appendix table 6B: Histogram of the PM2,5 concentrations.

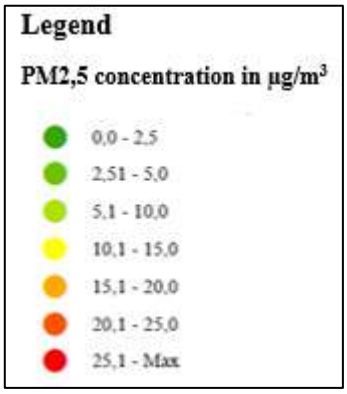
Appendix figure 6: Histogram of the distribution of PM concentrations measured with the PM sensor.

H. Appendix



Appendix figure 7: Legend for the PM10 concentration measurements.

From the collected data, maps were created in order to analyse the distribution of the data and to give a visual representation of the collected data. Appendix figure 7, shows the legend for the ArcMaps that contain the mobile measurements of the PM10 concentrations. As there was a large variation with the maximum concentrations that were measured. The maximum concentration here has been given as Max, the absolute maximum concentration is not considered to be of high importance here as the concentration is already above the threshold concentration. Appendix figure 9 and Appendix figure 10 show the PM10 concentrations that were measured during the rounds in period 1 and 2. The figures show within some rounds parts of the data is missing, this is due to a technical issue with the PM sensor. Overall, it can be seen that the largest amount of measurements has been made under the concentration of 20 µg/m^3. The PM10 concentrations are rarely measured above the threshold concentration of 50 µg/m^3. When the PM10 concentrations do exceed this threshold concentration, this does not occur for a long period of time.



Appendix figure 8: Legend for the PM2,5 concentration measurements.

Due to the large differences within the measured PM concentrations between PM10 and PM2,5 the two have been given different legends. Appendix figure 8 shows the legend for the PM2,5 concentrations that have been measured during the rounds. Like with the PM10 concentrations here the maximum measured concentration has also been given with Max and is different for each of the measured rounds. Appendix figure 11 and Appendix figure 12 show the PM2,5 concentration for each round, day and measuring period. It can be seen that there is much less variation in PM concentrations than with the PM10 concentrations.

Appendix figure 9A: ArcMap of the PM10 concentration distribution in period 1 on day 1 round 1 (P1D1R1). 12-03-2020

Appendix figure 9B: ArcMap of the PM10 concentration distribution in period 1 on day 1 round 2 (P1D1R2). 12-03-2020

Appendix figure 9C: ArcMap of the PM10 concentration distribution in period 1 on day 2 round 1 (P1D2R1). 17-03-2020

Appendix figure 9D: ArcMap of the PM10 concentration distribution in period 1 on day 2 round 2 (P1D2R2). 17-03-2020

Appendix figure 9E: ArcMap of the PM10 concentration distribution in period 1 on day 3 round 1 (P1D3R1). 25-03-2020

Appendix figure 9F: ArcMap of the PM10 concentration distribution in period 1 on day 3 round 2 (P1D3R2). 25-03-2020

Appendix figure 9: ArcMaps of the PM10 concentration distribution within the first measurement period in March.

Appendix figure 10A: ArcMap of the PM10 concentration distribution in period 2 on day 1 round 1 (P2D1R1). 08-05-2020

Appendix figure 10B: ArcMap of the PM10 concentration distribution in period 2 on day 1 round 2 (P2D1R2). 08-05-2020

Appendix figure 10C: ArcMap of the PM10 concentration distribution in period 2 on day 2 round 1 (P2D2R1). 20-05-2020

Appendix figure 10D: ArcMap of the PM10 concentration distribution in period 2 on day 2 round 2 (P2D2R2). 20-05-2020

Appendix figure 10E: ArcMap of the PM10 concentration distribution in period 2 on day 3 round 1 (P2D3R1). 29-05-2020

Appendix figure 10F: ArcMap of the PM10 concentration distribution in period 2 on day 3 round 2 (P2D3R2). 29-05-2020

Appendix figure 10: ArcMaps of the PM10 concentration distribution within the second measurement period in May.

Appendix figure 11A: ArcMap of the PM2,5 concentration distribution in period 1 on day 1 round 1 (P1D1R1). 12-03-2020

Appendix figure 11B: ArcMap of the PM2,5 concentration distribution in period 1 on day 1 round 2 (P1D1R2). 12-03-2020

Appendix figure 11C: ArcMap of the PM2,5 concentration distribution in period 1 on day 2 round 1 (P1D2R1). 17-03-2020

Appendix figure 11D: ArcMap of the PM2,5 concentration distribution in period 1 on day 2 round 2 (P1D2R2). 17-03-2020

Appendix figure 11E: ArcMap of the PM2,5 concentration distribution in period 1 on day 3 round 1 (P1D3R1). 25-03-2020

Appendix figure 11F: ArcMap of the PM2,5 concentration distribution in period 1 on day 3 round 2 (P1D3R2). 25-03-2020

Appendix figure 11: ArcMaps of the PM2,5 concentration distribution within the first measurement period in March.

Appendix figure 12A: ArcMap of the PM2,5 concentration distribution in period 2 on day 1 round 1 (P2D1R1). 08-05-2020

Appendix figure 12*B: ArcMap of the PM2,5 concentration distribution in period 2 on day 1 round 2 (P2D1R1). 08-05-2020*

Appendix figure 12*C: ArcMap of the PM2,5 concentration distribution in period 2 on day 2 round 1 (P2D2R1). 20-05-2020*

Appendix figure 12*D: ArcMap of the PM2,5 concentration distribution in period 2 on day 2 round 2 (P2D2R2). 20-05-2020*

Appendix figure 12*E: ArcMap of the PM2,5 concentration distribution in period 2 on day 3 round 1 (P2D3R1). 29-05-2020*

Appendix figure 12*F: ArcMap of the PM2,5 concentration distribution in period 2 on day 3 round 2 (P2D3R2). 29-05-2020*

Appendix figure 12: ArcMaps of the PM2,5 concentration distribution within the second measurement period in May.

I. Appendix

In order to analyse to what extent, the spatial distribution influence the PM concentration, 3 different locations were analysed and compared to each other. These three different locations were, location number 1 an urban park, location number 2 the large highway (A23), and lastly location number 3, a smaller road. Al locations are measured over a length of 600m. location nr 2 has the middle point in the middle of the highway A23 with 300m before and 300m after this middle point.

As Appendix G shows, the PM concentration data that has been collected is not normally distributed. Therefore, the Mann-Whitney U test will be used to analyse the data in order to see on which of the locations the highest PM concentration data can be found.

Appendix table 14: The output for the Mann-Whitney U test looking at the different location and the PM10 concentrations.

	N	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
Park	368	281,65	103645,50			
Highway	417	491,27 [b]	204859,50			
	785			35749,500	-12,926	0,000 [a]
Park	368	271,74	100002,00			
Road	285	398,35 [b]	113529,00			
	653			32106,000	-8,505	0,000 [a]
Highway	417	370,57 [b]	154526,50			
Road	285	323,60	92226,50			
	702			51471,500	-3,013	0,003 [a]

[a] Significant difference are displayed at p=0,05

[b] Highest of the measured mean ranks

Appendix table 14 and Appendix table 15 show the output of the Mann-Whitney U test for the PM10 and PM2,5 concentrations on the different locations.

Appendix table 15: The output for the Mann-Whitney U test looking at the different location and the PM2,5 concentrations.

	N	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
Park	368	312,98	115177,00			
Highway	417	463,62[b]	193328,00			
	785			47281,000	-9,290	0,000[a]
Park	368	285,60 [b]	105101,00			
Road	285	380,46	108430,00			
	653			37205,000	-6,373	0,000 [a]
Highway	417	352,98 [b]	147194,00			
Road	285	349,33	99559,00			
	702			58804,000	-,234	0,815

[a] Significant difference are displayed at p=0,05

[b] Highest of the measured mean ranks

J. Appendix

Output for the Mann-Whitney U test for collected data, looking at the significant differences between the measured rounds.

Appendix Table 16: The output for the Mann-Whitney-U test to analyse the significant differences between the PM10 concentrations in the different rounds of data taken within a day.

Period	Round of the day	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Period 1							
Day 1	Round 1	592	661,26	391464,50			
12-03-2020	Round 2	782	707,37 [b]	553160,50			
		1374			215936,500	-2,133	0,033
Day 2	Round 1	733	612,69	449098,50			
17-03-2020	Round 2	765	880,59 [b]	673652,50			
		1498			180087,500	-11,983	0,000 [a]
Day 3	Round 1	733	622,14	456029,50			
25-03-2020	Round 2	708	823,35 [b]	582931,50			
		1441			187018,500	-9,176	0,000[a]
Period 2							
Day 1	Round 1	742	1034,18 [b]	767365,00			
08-05-2020	Round 2	783	506,02	396210,00			
		1425			89274,000	-23,410	0,000 [a]
Day 2	Round 1	272	316,53	86096,00			
20-05-2020	Round 2	587	482,58 [b]	283274,00			
		859			48968,000	-9,125	0,000 [a]
Day 3	Round 1	399	396,34	158141,00			
29-05-2020	Round 2	807	705,92 [b]	569680,00			
		1206			78341,000	-14,525	0,000 [a]

[a] Significant difference are displayed at p=0,05.

[b] Highest of the measured mean ranks

Appendix Table 16 shows the output of the Mann-Whitney U test for the PM10 concentrations that have been measured on the different days.

Appendix Table 17 shows the output for the Mann-Whitney U test for the PM2,5 concentrations on the different measurement days.

Appendix Table 17: The output for the Mann-Whitney U test to analyse the significant differences between the PM2,5 concentrations in the different rounds of data taken within a day.

Period	Round of the day	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Period 1							
Day 1	Round 1	592	697,07 [b]	412666,50			
12-03-2020	Round 2	782	680,25	531958,50			
		1374			225805,500	-0,779	0,436
Day 2	Round 1	733	521,84	382507,00			
17-03-2020	Round 2	765	967,64 [b]	740244,00			
		1498			113496,000	-19,942	0,000 [a]
Day 3	Round 1	733	618,95	453693,50			
25-03-2020	Round 2	708	826,65 [b]	585267,50			
		1441			184682,500	-9,475	0,000 [a]
Period 2							
Day 1	Round 1	742	1085,59 [b]	805507,00			
08-05-2020	Round 2	783	457,30	358068,00			
		1525			51132,000	-27,854	0,000 [a]
Day 2	Round 1	272	255,67	69541,50			
20-05-2020	Round 2	587	510,78 [b]	299828,50			
		859			32413,500	-14,043	0,000 [a]
Day 3	Round 1	399	290,09	115747,50			
29-05-2020	Round 2	807	758,46 [b]	612073,50			
		1206			35947,500	-21,994	0,000 [a]

[a] Significant difference are displayed at p=0,05

[b] Highest of the measured mean ranks

K. Appendix

The output for the Mann-Whitney U test comparing the PM concentrations on different days. Appendix Table 18 shows the output for the Mann-Whitney U test, comparing the output of the PM concentrations measured on the different measurement days, each compared to each other in order to analyse significant differences between the measurement days and in order to see on which day the highest PM10 concentrations were measured.

Appendix Table 18: Output for the Mann-Whitney U test comparing the PM10 concentrations in $\mu g \cdot m^{-3}$ measured on different days to test which day has the highest PM concentrations

Day	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)

1	1357	793,74	1077107,50			
2	1498	2002,56 [b]	2999832,50			
	2855			155704,500	-39,131	0,000 [a]
1	1357	991,06	1344863,00			
3	1441	1784,13 [b]	2570938,00			
	2798			423460,000	-25,953	0,000 [a]
1	1357	972,27	1319366,50			
4	1525	1859,04 [b]	2835036,50			
	2882			397963,500	-28,558	0,000 [a]
1	1357	908,60	1232968,00			
5	859	1424,29 [b]	1223468,00			
	2216			311565,000	-18,486	0,000 [a]
1	1357	1006,86	1366312,50			
6	1198	1585,12 [b]	1898977,50			
	2555			444909,500	-19,773	0,000 [a]
2	1498	1969,59 [b]	2950439,00			
3	1441	950,65	1369891,00			
	2939			330930,000	-32,543	0,000 [a]
2	1498	1798,43 [b]	2694047,50			
4	1525	1230,64	1876728,50			
	3023			713153,500	-17,883	0,000 [a]
2	1498	1544,39 [b]	2313498,00			
5	859	541,80	465405,00			
	2357			96035,000	-34,422	0,000 [a]
2	1498	1853,39 [b]	2776379,00			
6	1198	717,18	859177,00			
	2696			140976,000	-37,660	0,000 [a]
3	1441	1259,63	1815122,50			
4	1525	1695,04 [b]	2584938,50			
	2966			776161,500	-13,840	0,000 [a]
3	1441	1273,47 [b]	1835064,00			
5	859	944,22	811086,00			
	2300			441716,000	-11,502	0,000 [a]
3	1441	1480,30 [b]	2133108,50			
6	1198	1127,19	1350371,50			
	2639			632170,500	-11,853	0,000 [a]
4	1525	1394,06 [b]	2125934,50			
5	859	834,67	716985,50			
	2384			347615,500	-19,050	0,000 [a]
4	1525	1635,42 [b]	2494020,00			
6	1198	1013,94	1214706,00			
	2723			496505,000	-20,476	0,000 [a]
5	859	1003,09	861653,00			
6	1198	1047,58 [b]	1255000,00			
	2057			492283,000	-1,676	0,094

[a] Significant difference are displayed

[b] Highest of the measured mean ranks

In Appendix Table 18 shows the output of the Mann-Witney U test for the PM10 concentrations comparing each day to each other.

Appendix Table 19 shows a summary of Appendix Table 18.

Appendix Table 19: Summary of the Mann-Whitney U test looking at the different PM10 concentrations measured on the different days compared to each other.

	Day	Period 1			Period 2		
		1	2	3	4	5	6
Period 1	1						
	2	0,000					
	3	0,000	0,000				
Period 2	4	0,000	0,000	0,000			
	5	0,000	0,000	0,000	0,000		
	6	0,000	0,000	0,000	0,000	0,094	

[a] Significant difference are displayed

Appendix table 20: Output for the Mann-Whitney U test comparing the PM2,5 concentrations in µg·m^{-3} measured on different days to test which day has the highest PM concentrations

Day	*N*	*Mean Rank*	*Sum of Ranks*	*Mann-Whitney U*	*Z*	*Asymp. Sig. (2-tailed)*
1	1357	682,50	926156,50			
2	1498	2103,33 [b]	3150783,50			
	2855			4753,500	-46,003	0,000 [a]
1	1357	716,31	972038,50			
3	1441	2042,86 [b]	2943762,50			
	2798			50635,500	-43,422	0,000 [a]
1	1357	722,11	979899,50			
4	1525	2081,64 [b]	3174503,50			
	2882			58496,500	-43,793	0,000 [a]
1	1357	691,11	937833,50			
5	859	1767,87 [b]	1518602,50			
	2216			16430,500	-38,617	0,000 [a]
1	1357	724,63	983318,50			
6	1198	1904,82 [b]	2281971,50			
	2555			61915,500	-40,371	0,000 [a]
2	1498	2095,09 [b]	3138439,50			
3	1441	820,19	1181890,50			
	2939			142929,500	-40,721	0,000 [a]
2	1498	1771,12 [b]	2653133,50			
4	1525	1257,47	1917642,50			

	3023			754067,500	-16,180	0,000 [a]
2	1498	1582,88 [b]	2371148,50			
5	859	474,69	407754,50			
	2357			38384,500	-38,053	0,000 [a]
2	1498	1923,97 [b]	2882112,00			
6	1198	628,92	753444,00			
	2696			35243,000	-42,930	0,000 [a]
3	1441	1135,99	1636957,50			
4	1525	1811,87 [b]	2763103,50			
	2966			597996,500	-21,486	0,000 [a]
3	1441	1192,83 [b]	1718868,00			
5	859	1079,49	927282,00			
	2300			557912,000	-3,961	0,000 [a]
3	1441	1487,04 [b]	2142825,00			
6	1198	1119,08	1340655,00			
	2639			622454,000	-12,356	0,000 [a]
4	1525	1389,77 [b]	2119405,00			
5	859	842,28	723515,00			
	2384			354145,000	-18,649	0,000 [a]
4	1525	1684,73 [b]	2569217,00			
6	1198	951,18	1139509,00			
	2723			421308,000	-24,173	0,000 [a]
5	859	1191,75 [b]	1023717,50			
6	1198	912,30	1092935,50			
	2057			374734,500	-10,536	0,000 [a]

[a] Significant difference are displayed at p=0,05.

[b] Highest of the measured mean ranks

In Appendix table 20 shows the output of the Mann-Witney U test for the PM10 concentrations comparing each day to each other. Appendix table 21 shows a summary of Appendix table 20.

Appendix table 21: Summary of the Mann-Whitney U test looking at the different PM2,5 concentrations measured on the different days compared to each other.

		Period 1			Period 2		
	Day	1	2	3	4	5	6
Period 1	1						
	2	0,000					
	3	0,000	0,000				
Period 2	4	0,000	0,000	0,000			
	5	0,000	0,000	0,000	0,000		
	6	0,000	0,000	0,000	0,000	0,000	

In Appendix table 22 PM10 and PM2,5 concentrations and the different measurement periods. Period 1 are the measurement made in March and period 2 are the measurements made in May.

Appendix table 22: Output for the Mann-Whitney U test to test if there is a significant difference between the PM concentrations measured in the two different periods.

	Period	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
PM10	1	4296	4065,75 [b]	17466477,50			
	2	3582	3788,08	13568903,50			
		7878			7151750,500	-5,396	0,000 [a]
PM2,5	1	4296	3791,13	16286707,00			
	2	3582	4117,44 [b]	14748674,00			
		7878			7056751,000	-6,342	0,000 [a]

[a] Significant difference are displayed at p=0,05.
[b] Highest of the measured mean ranks

L. Appendix

The meteorological conditions have been made available for the six different measurement days. These meteorological conditions are shown in Appendix table 23.

Appendix table 23: Meteorological conditions of the 6 measurement days in the 2 periods.

		Period 1			Period 2		
		12.03	17.03	25.03	08.05	20.05	29.05
Wind direction		N/E	N/E	S/E	Undefined	Undefined	Undefined
Wind speed (m/s)		13,51	4,90	8,58	4,828	13,31	11,34
Cyclonic or anticyclonic conditions	At 925hPa	A	C	C	C	C	C
	At 500hPa	A	A	A	A	C	C
Humidity conditions		D	W	D	W	D	W
Precipitation in (mm)		0,00	0,00	0,00	0,00	0,00	0,77 [a]

[a] precipitation event occurred after measurements were taken