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Assessing the Effect of Traffic Density and Cold Airflows on the Urban Air Quality of a City with Complex Topography Using Continuous Measurements

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Abstract: The air quality in cities is affected by many factors such as topography, weather, emission sources, etc. In order to assess the influence of these factors on a certain location, continuous measurements of air quality as well as meteorological parameters are essential. The city of Stuttgart in Germany is known for its unique topography and air quality problems making it a very interesting place to investigate the impact of topography and thermal induced wind systems on the air quality. Stuttgart city center is surrounded by hills, elevated plains where cold air masses are produced during nights with autochthonous weather situations. Due to the varying topography, these cold air masses stream through valleys and gullies into the city centre. In this study, a stationary monitoring station was installed at Marienplatz, Stuttgart where the cold airflows from the valleys and gullies are collected together and enter the city, hence making it the optimum location for this investigation. The air pollutants such as nitrogen oxides (NO_X, NO, NO_2), ozone (O_3), carbon monoxide (CO), Particulate Matter (PM) and Black Carbon (BC) were monitored continuously along with the meteorological parameters such as air temperature, relative humidity, air pressure, wind speed, wind direction, precipitation intensity and global radiation from March 2017 till now. In this paper, the results from March 2017 until December 2019 are presented. The influence of wind speed and wind direction on the concentration of pollutants is interpreted using wind and pollution roses. Temperature roses are plotted to understand the effect of cold airflows that bring fresh and cold air into the city. The traffic data for the federal highway passing by the monitoring station are obtained and the pollutant concentrations are related to the traffic, as it is the dominant source of emission in the city.

Key words: air quality monitoring, cold airflows, urban air quality, traffic and air quality, air pollution in Stuttgart, continuous measurements, air pollutants

1. Introduction

Air pollution is an important environmental and social problem. The quality of air is deteriorating with increase in anthropogenic and natural activities emitting various agents of air pollution [1]. In Europe, the emissions of many air pollutants have declined since 1990 resulting in improved air quality. However, air pollutant concentrations are still higher in cities, e.g., in Stuttgart, which is the sixth largest city in Germany with a population of around 630,000 [2]. The city is known for its unique topography and makes it interesting to study the effects of pollutants as the reduction in the wind velocity causes hindrance for pollutant dispersion resulting in higher pollutant concentrations [3].

The objective of the research was to investigate the cold airflows coming into the city and to interpret the meteorological influence on the pollutant concentration as well as to study the effect of traffic on the pollutant concentrations. This was done using the results obtained from the monitoring station installed at Marienplatz, Stuttgart for the period of March 2017 until December 2019.

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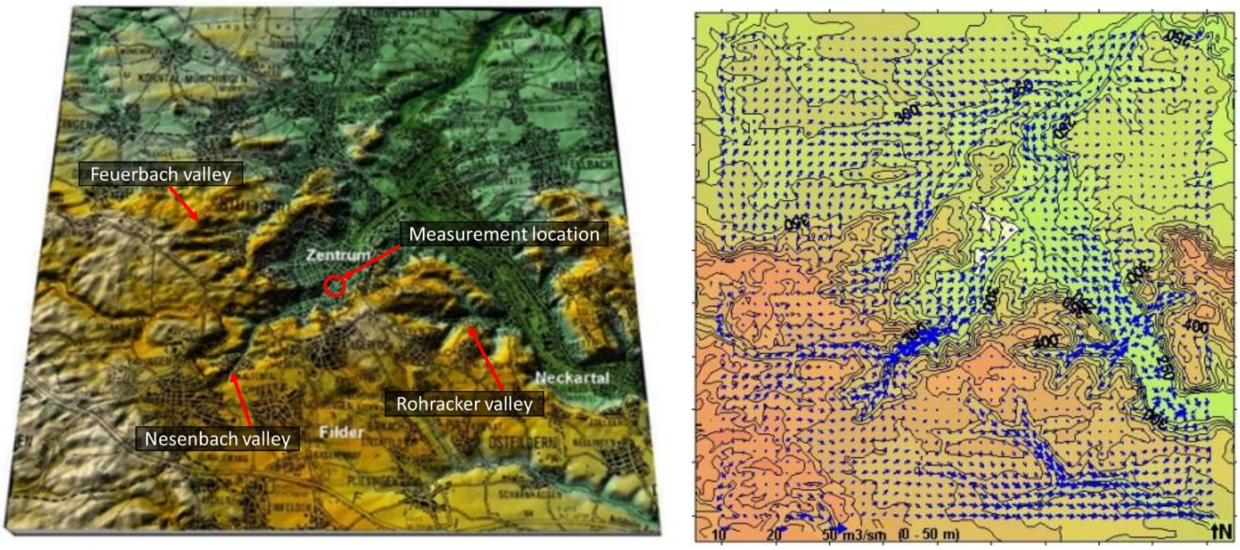
1.1 Cold Airflows and Topography

Local wind systems play an important role in defining the urban climate. These are formed in valleys and at slopes because of the change in air temperature, air pressure and shielding effect of the surrounding mountain ranges. The wind systems even with low wind speed, play a serious role in the aeration of Stuttgart. Fig. 1(a) shows the topographical situation of Stuttgart's city basin [3]. Stuttgart's city basin consists of Nesenbach valley and west basin. These two parts are separated by a ledge, which forms the southern border of the wind-sheltered west basin. On the other side, the ledge increases the wind in the Nesenbach valley, towards the city center. The ridge, which divides parallel the Feuerbach valley and the Stuttgart's city basin, also affects the climate.

Fig. 1(b) shows the results of a simulation performed for the cold airflows and the distribution of wind speeds in Stuttgart's basin valley. The maximum wind speed is 3 m/s with the highest wind speeds reached at Nesenbach valley and Rohracker valley. However, the amount of cold air is more crucial than the wind speed in this situation. Since all valleys are cold air catchment areas, it can be seen that the volume flow density are higher at valleys [4].



(a) (b)

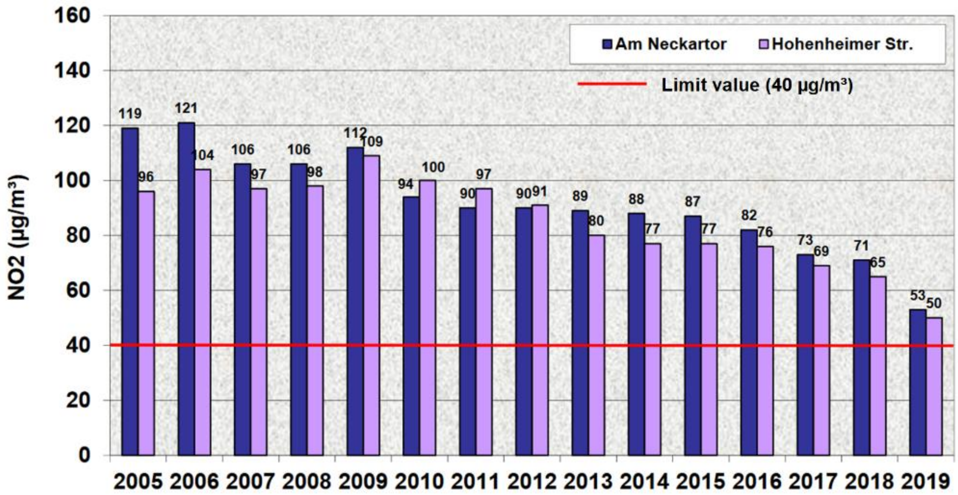
Fig. 1 a) Topographic situation of Stuttgart's city basin, b) results of a cold airflow simulation in Stuttgart [3, 4].

1.2 Air Quality Situation in Stuttgart

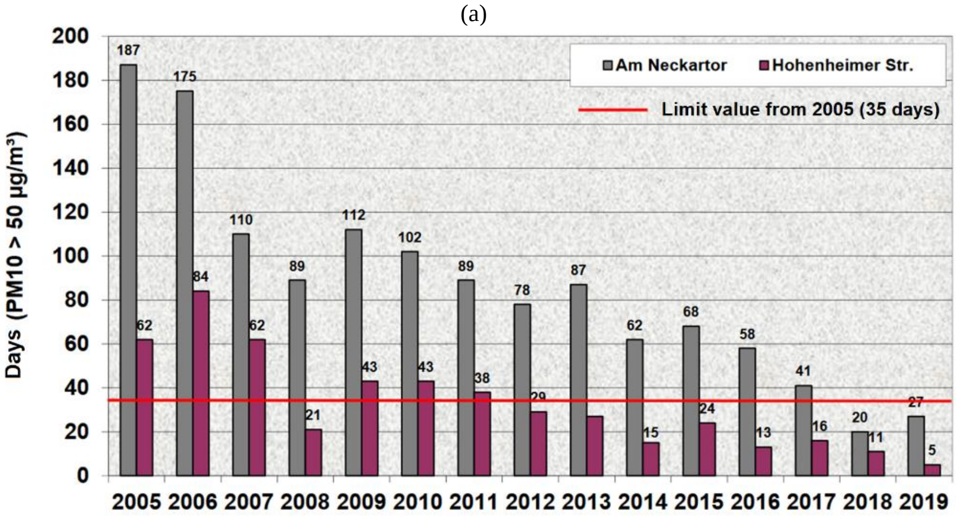
The "State Institute for the Environment, Baden-Württemberg" (LUBW) is responsible for the operation and maintenance of the ambient air monitoring network. The relevant air pollutants are measured at five monitoring stations in Stuttgart which include urban background and traffic monitoring stations [5]. In addition to the permanent monitoring stations, so-called hotspot monitoring stations are installed at selected locations, which are considered to be the hotspots of air pollution. The purpose of the hotspot monitoring stations in Stuttgart is the detection of traffic-related air pollution at urban stress centers. In Stuttgart, there are currently two hotspot monitoring stations namely Stuttgart Hohenheimer Straße and Stuttgart Am Neckartor [5]. The monitoring station Stuttgart Am Neckartor which is close to the city center on the busy federal highway B14 is already in frequent focus of professional world and society as at this monitoring station the highest NO_2 and PM10 pollution levels in the whole Germany were measured in the recent years [6]. Both the measurement stations *Stuttgart Am Neckartor* and *Hohenheimer Straße* are within 5 km radius of the monitoring station

Marienplatz where the continuous measurements were done which are described in this paper.

The "Federal Immission Control Ordinance" (39th BImSchV) which implements the European Directive 2008/50/EC into German law sets the following limit values for NO_2: The hourly average NO_2 concentration must not exceed the limit value of 200 μg/m³ for more than 18 times a year. The annual mean concentration of NO_2 must not be higher than 40 μg/m³. Fig. 2(a) shows the NO_2 annual average concentrations at the LUBW monitoring station *Stuttgart Am Neckartor* and *Hohenheimer Straße* in the period from 2004 to 2019 [7]. It can be seen that the NO_2 annual average concentrations at the monitoring station *Stuttgart Am Neckartor* ranged permanently between 71 and 121 μg/m³, i.e., by a factor of around 2 to 3 above the permitted limit. The permitted limit was also clearly exceeded at the other hotspot monitoring station *Hohenheimer Straße*.



(a)



(b)

Fig. 2 (a) Annual mean NO_2 concentration and (b) Number of days exceeding the PM10 daily average value of 50 µg/m³ at the LUBW monitoring stations *Am Neckartor* and *Hohenheimer Straße* in Stuttgart from 2004 to 2019 [7].

The ambient air limit values for PM10 and PM2.5 are also defined in the above mentioned ordinance. The long term ambient air limit value averaged over one calendar year for PM10 is 40 μg/m³ and for PM2.5 is 25 μg/m³ which is valid since 2015. The short term ambient air limit value is the daily average value for PM10 which is 50 μg/m³. It must not be exceeded 35 times in one calendar year (Directive 2008/50/EC and

39. BImSchV). The counts of days with exceeding daily mean PM10 concentration at two Stuttgart hotspot monitoring stations for the years 2004 to 2019 is shown in Fig. 2(b). As late as 2005, the daily limit value of PM10, which is 50 μg/m³, was exceeded on 187 days in this year at the monitoring station *Am Neckartor* when a maximum of 35 days of exceedance was allowed per year. However, a decreasing trend of exceedances can be clearly observed. Only in the last two years, the number of exceedances at the monitoring station *Am Neckartor* was below the allowed limit of 35 exceeding days per year.

1.3 Traffic as a Source of Emission

Investigations done by LUBW in 2016 on the calculation of the contribution of different emission sources at the location of *Stuttgart Am Neckartor* have shown that 52% of the NO_2 concentration at this location is attributable to the local road traffic. The contribution to air pollution from the local sources (local road traffic, small and medium combustion plants, others, etc.) is very high with 56% as compared to the air pollution caused by sources from regional and urban background [8]. For PM10, at the location Am Neckartor, 47% of the emission is caused by local road traffic (exhaust fumes, abrasion and re-suspension) and approx. 2% by small and medium combustion plants and less than 1% by industry. The remaining 50% are to be assigned to the overall background level which is the combination of urban and large-scale background sources [8].

The federal highway B14, which passes directly by the hotspot monitoring station Am Neckartor, is an important traffic pathway in the area of Stuttgart. It consists of two directions of travel and has three lanes in each direction. On some sections later, the road has up to five lanes in each direction. According to a traffic survey conducted by the LUBW in 2018, around 70,000 vehicles on average pass by the monitoring station Am Neckartor each day. The share of heavy commercial vehicles is around 3.0%. On a Sunday, the average daily traffic decreases by up to 31% and the share of heavy commercial vehicles even decrease down to around 0.4% from 3.0% [8]. The Fig. 3 shows

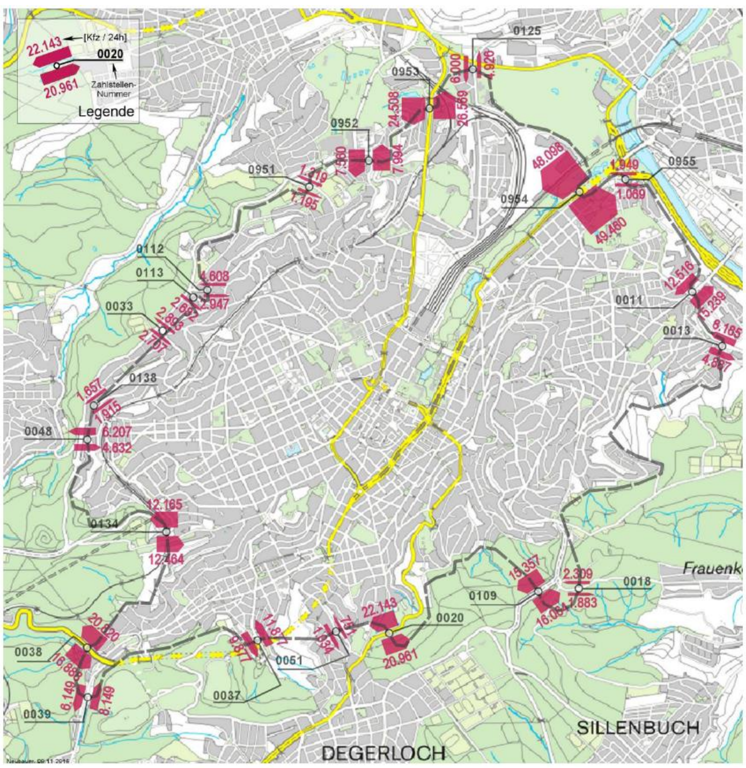


Fig. 3 Number of vehicles per day coming in and out of the city in the year 2015 [9].

the average number of vehicles per day coming in and out of the city in the year 2015 [9]. It can be seen that only on the two federal highways B14 and B27, there are around 150,000 vehicles per day that enter or leave the city. This situation clearly indicates the air quality problem in the city of Stuttgart due to vehicular emissions.

2. Measurement Technique and Methodology

This study aims to investigate the air quality of an urban city and certain effects relating to it such as topography, cold airflows and traffic. A monitoring station was installed in order to measure air pollutants and meteorological parameters at Marienplatz, Stuttgart from March 2017.

2.1 Measurement Location

The uniqueness in topography of Stuttgart results in different monitoring stations being set up at different locations to be able to monitor the air quality and pollutant levels. Marienplatz located in the path of cold airflows emerging from Nesenbachtal and proceeding towards the city, is a crucial location to monitor the air pollutants and meteorological parameters. In order to investigate these thermal wind system and pollutant concentrations associated with these, a continuously operating monitoring station was installed at Marienplatz. The monitored air pollutants were namely nitrogen oxides (NO_X, NO, NO_2), ozone (O_3), carbon monoxide (CO), Particulate Matter (PM) and Black Carbon (BC). The measured meteorological parameters were the air temperature, relative humidity, air pressure, wind speed, wind direction, precipitation intensity and global radiation. Fig. 4 shows the location of the monitoring station highlighted with red circle. The measurement location is also shown in the Fig. 1(a) using the topographic map of Stuttgart.

Fig. 4 Location of monitoring station (red circle) at Marienplatz, Stuttgart.

2.2 Measurement Setup

The measurements were performed continuously with a time resolution of one second. The devices used for measuring the air pollutants and meteorological parameters are listed in the Table 1 and Table 2 respectively.

The monitoring station in the form of a measurement car can be seen in the Fig. 5(a). Fig. 5(b) shows the devices for measuring pollutants and Fig. 5(c) shows the devices for measuring meteorological parameters.

Table 1 List of devices used for measuring air pollutants at the monitoring station Marienplatz, Stuttgart.

Instrument	Measurement principle	Measured parameters	Accuracy	Resolution
Aerosol spectrometer	Light scattering	Particulate Matter (PM) with size range 0.25-32 µm	5%	0.1 µg/m^3
Aethalometer	Light attenuation	Black Carbon (BC)	30 ng/m^3	1 ng/m^3
NO_2/NO/NO_X monitor	Chemiluminiscence	NO_2, NO, NO_X	0.5%	0.1 ppb
Ozone monitor	UV absorption	O_3	2%	0.1 ppb
CO monitor	NDIR absorption	CO	1%	0.1 ppm

Table 2 List of devices used for measuring meteorological parameters at the monitoring station Marienplatz, Stuttgart.

Instrument	Measurement principle	Measured parameter	Accuracy	Resolution
Weather station	Negative Temperature Coefficient (NTC) resistor	Air temperature	0.5ºC	0.1ºC
	Capacitive humidity sensor	Relative humidity	5%	0.1%
	Micro Electro Mechanical Sensor (MEMS)	Atmospheric pressure	1.5 hPa	0.1 hPa
	Pyranometer	Global radiation	2%	1 W/m^2
Wind sensor	Ultrasonic time of flight	Wind speed	0.2 m/s	0.1 m/s
	Ultrasonic time of flight	Wind direction	10º	1º
Precipitation sensor	Tipping bucket system	Precipitation intensity	2%	2 cm^3

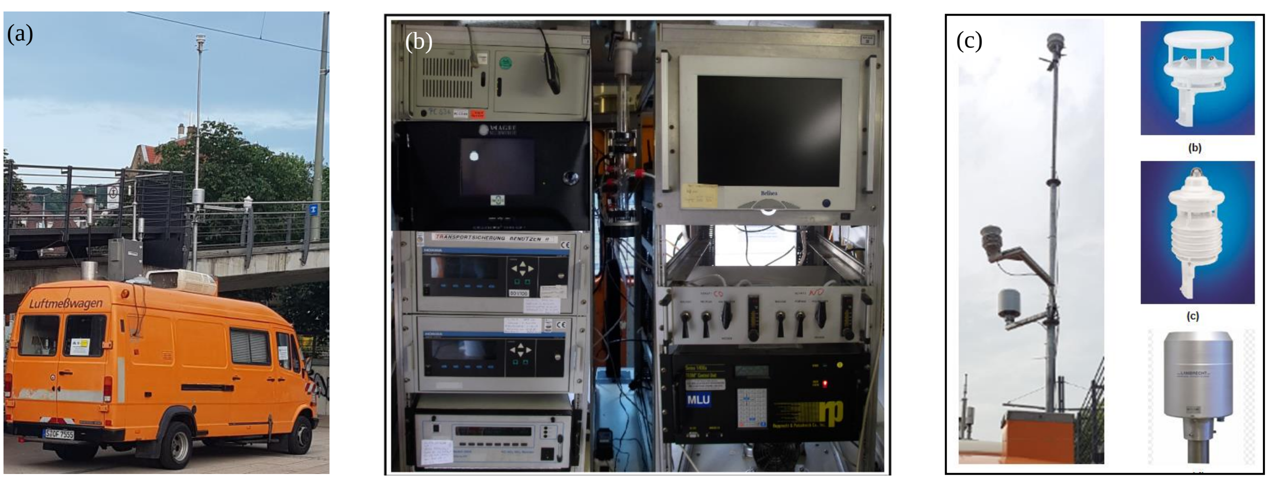


Fig. 5 (a) Monitoring station, (b) devices in the monitoring station for measuring air pollutants and (c) devices in the monitoring station for measuring meteorological parameters.

3. Results and Discussion

The evaluation of the data obtained from the monitoring station at Marienplatz is done for the period of March 2017 until December 2019. The focus of evaluation was on assessing the effect of cold airflows and traffic on the air quality of the area under investigation.

3.1 Cold Airflows

The two important factors that need to be measured in order to investigate the cold airflows are the wind (direction and speed) and air temperature at different points in the path of cold airflows. With the help of these two parameters the cold airflows can be identified. The results of wind and temperature measured at the monitoring station are shown in the section below.

3.1.1 Wind Direction

The results of the wind measurements are presented in the form of a wind rose which is a graphical interpretation of wind direction and wind speed. The wind rose for the complete evaluation period from March 2017 to December 2019 is shown in the Fig. 6. It can be seen that a dominating part of the wind came from the west southwest direction with a wind speed below 1.5 m/s. Overall the wind speed varied between 0-4 m/s with a mean wind speed of around 1 m/s for the whole measurement period. Fig. 6 interprets that approximately 60% of the total wind came from west and southwest direction. Around 15% of the time, the wind came from the northeast direction. This is the wind coming from the city towards Marienplatz. The wind speed below 0.5 m/s is represented as calms which was 6.7% of the whole period.

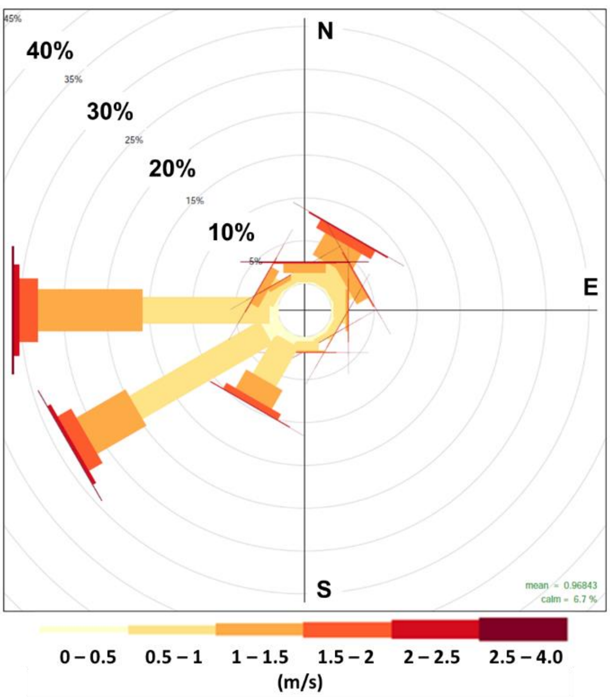


Fig. 6 Wind rose average measured at Marienplatz monitoring station between March 2017 and December 2019.

These results confirm that for around 75% of the total time, the wind came from the area between south and west that is the same area where the slopes come down and open up into the city. The air coming from this direction was cooler as its origin is from higher altitude, from plains where cold air is produced during autochthonous weather situations as compared to the air close to the city that was warmer because of missing cold airflows from that direction and because of the urban heat island effect.

The wind rose presented in the Fig. 6 was divided in separated wind roses for each hour of the day in Fig. 7. This representation helps to understand how the wind speed and wind direction change during the day at the monitoring station. It can be seen from the result that the wind direction is different during the night and during the day. During the night from 7 P.M. to 8 A.M. in the morning, the dominated wind direction was west southwest while during the day from 9 A.M. until 6 P.M., a significant amount of wind came from northeast. The wind speed during the daytime was around 0.5 m/s higher than the wind speed during the night.

3.1.2 Temperature Rose

The temperature rose gives an idea of the air temperature of the air masses when they are coming from the respective direction. In that way it can be identified that the wind coming from a certain direction is cooler or warmer as compared to the wind coming from the other directions. Fig. 8 depicts the overall temperature rose for entire evaluation period, during which the maximum hourly average air temperature of 18°C was observed from north and minimum hourly average temperature of 10°C from southwest. It has been observed in previous studies as well that the wind with the coldest temperatures blows from southwest elevated terrains, wooded ridges and vegetation areas characterized by cold air flowing over valleys leading to the basins of the inner city [10]. This was observed with the results obtained from the monitoring station as the air coming from southwest was around 5°C cooler as compared to the air coming from the opposite direction.

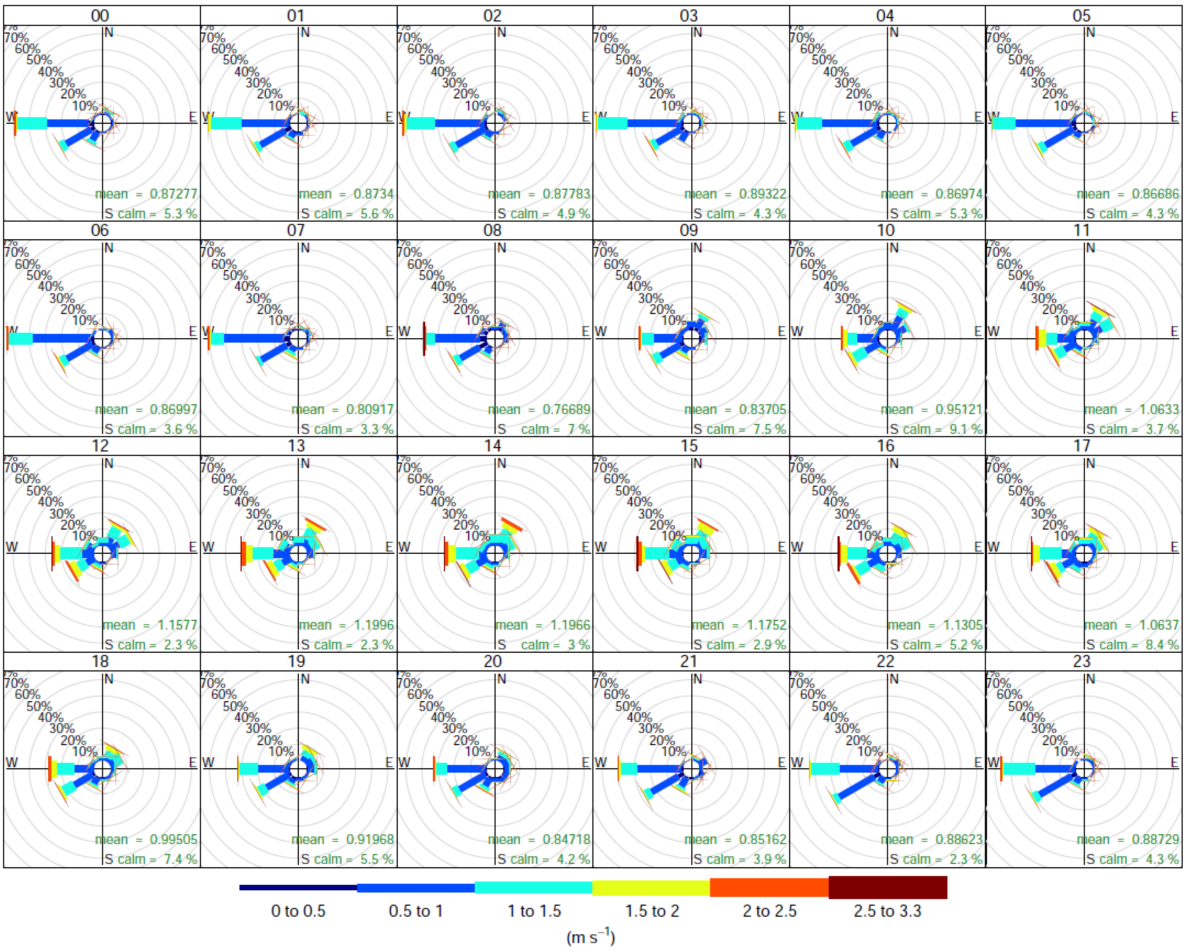


Fig. 7 Wind rose hourly average measured at Marienplatz monitoring station between March 2017 and December 2019.

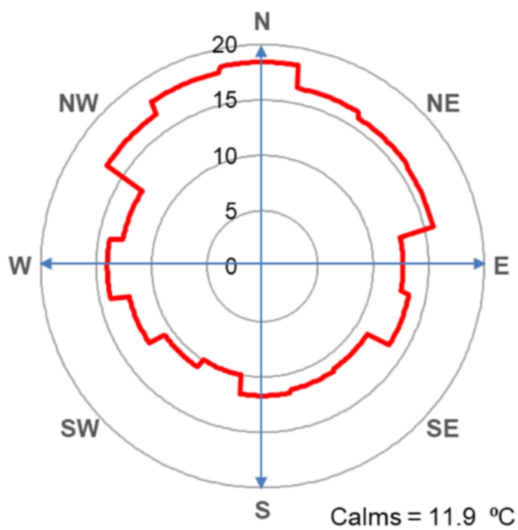


Fig. 8 Temperature rose hourly average measured at Marienplatz monitoring station between March 2017 and December 2019.

3.2 Influence of Traffic

The local traffic plays an important role in the air quality of the city. It is the major source of emission in the investigated area as explained in the introduction section.

3.2.1 Pollution Rose

In order to investigate the effect of traffic on the pollutant concentration, pollution roses are very helpful. In the pollution rose, pollutants are represented as function of wind direction for wind speed greater than 0.5 m/s. With pollution roses it is possible to identify the direction from where the polluted air is coming. In this study it was observed that the concentrations of the measured pollutant were higher when the air was coming from northeast and southeast direction which is the direct implication from road traffic. The pollution rose for NO_2 is shown as an example in the Fig. 9 in which it can be observed that the NO_2 concentration measured at the monitoring station was around 1.5 times higher when the wind was coming from the northeast, east and southeast as compared to the NO_2 concentration when the wind was coming from south, southwest and west. NO_2 concentration of around 40 μg/m^3 was monitored when the wind came from east and around 30 μg/m^3 when the wind came from west. The other pollutants behaved similarly but the difference in concentrations when the wind was coming from the city side or from the valley side was not as high as for NO_2. The NO_2 concentration was relatively high during the calms because of the reason that the transport of pollutants is limited during very low wind speeds.

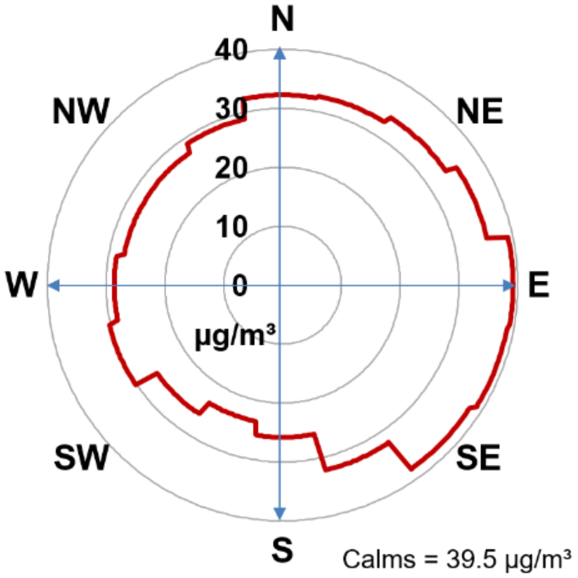


Fig. 9 Pollution rose for NO_2 from the monitoring station at Marienplatz for the period between March 2017 and December 2019.

3.2.2 Photochemical Equation

The pollutants NO, NO_2 and O_3 take part in the atmospheric photochemical reaction. NO is a primary air pollutant while O_3 is a secondary pollutant that forms during chemical reactions. NO_2 however is emitted directly as well as formed during chemical reactions making it both primary and secondary pollutant. The presence of sunlight induces the photochemical reaction in which NO_2 is converted to NO (Eq. (1)) as the result of photolysis which leads to a rise in O_3 concentration (Eq. (2)). NO is converted to NO_2 reacting with O_3 (Eq. (3)). NO can convert within seconds to minutes into NO_2 in the presence of O_3. Besides traffic and other anthropogenic activities, the mixing height over the city also has an influence on air pollutant concentrations [11].

Conversion of NO, NO_2 and O_3 are well established happens according to the following reactions [12]:

$$NO_2 + hv \rightarrow NO + [O] \tag{1}$$

$$[O] + O_2 \rightarrow O_3 + M \tag{2}$$

$$O_3 + NO \leftrightarrow NO_2 + O_2 \tag{3}$$

Where M is a molecule, which absorbs the excess vibrational energy and thus stabilizes the ozone molecule formed; hv is the energy of a photon with a wavelength less than 424 nm; $[O]$ is an active monoatomic oxygen molecule.

The hourly concentration distribution of NO, NO_2 and O_3 monitored at Marienplatz for the monitoring period between March 2017 and December 2019 is shown in the Fig. 10. The results shown here are the hourly average concentrations of the respective pollutant.

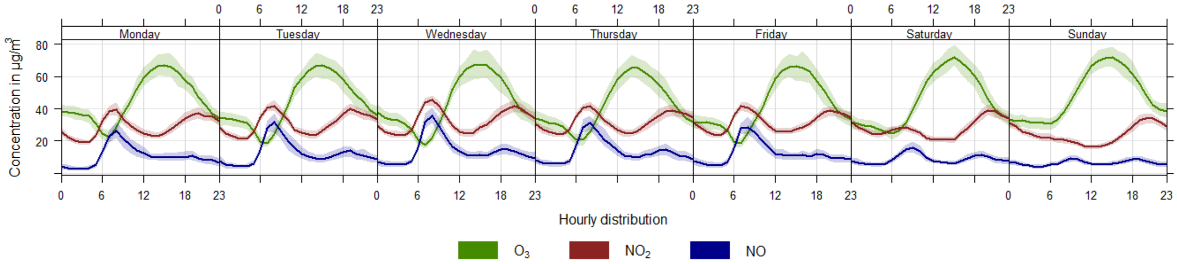


Fig. 10 Hourly concentration distribution of NO, NO_2 and O_3 for the period between March 2017 and December 2019.

From the hourly concentration distribution, it can be interpreted that NO and NO_2 concentrations during early morning hours at 3 A.M. were approximately 5 µg/m^3 and 25 µg/m^3 respectively. The concentration increased during the rush hours and the maximum peak was observed at around 8 A.M. having NO and NO_2 concentrations of almost 25 µg/m^3 and 40 µg/m^3 respectively. Meanwhile O_3 concentration started with above 30 µg/m^3 at 3 A.M., which then depleted during the rush hour due to oxidation of NO to NO_2 with consumption of O_3 and reached the minimum of approx. 20 µg/m^3. The O_3 concentration increased during the day and reached a maximum of circa 70 µg/m^3 at around 3 P.M. The NO concentration decreased as it reacted with O_3 forming NO_2. The rush hour peak in the evening started at around 4 P.M. and showed a peak for NO and NO_2 with a concentration of just below 15 µg/m^3 and 40 µg/m^3 respectively at around 7 P.M. The evening peak was less intense than the morning peak for NO as the people left the workplace at varied time in the evening that is an assumption based on the traffic data. In the night at 11 P.M. the NO concentration was below 10 µg/m^3 while both the NO_2 and O_3 concentrations around 35 µg/m^3.

3.2.2 Traffic Intensity and Pollutant Behaviour

The pollutant concentrations and the traffic intensity are closely related to each other. Hence, a comparison was done relating the traffic intensity and pollutant concentrations. The traffic data were obtained from the responsible authorities. This data were related to the measured pollutant concentrations in order to study the correlation between them. The average number of vehicles passing by close to the monitoring station at Marienplatz during the whole period between March 2017 and December 2019 are shown in Fig. 11. For this evaluation both the federal highway B14 and the main road Filderstraße as marked in Fig. 4 are considered. The solid line represents the median, the darker shade represents 25th and 75th quantiles and the lighter shade represents the 5th and 95th quantiles.

As expected, more vehicles were passing by the monitoring station on the weekdays compared to the weekends. On the weekdays, the rush hour traffic was also noticeable in the morning between 7 to 9 A.M. and in the evening between 4 to 7 P.M. The average number of vehicles per hour during the rush hours on the weekdays was around 3500 to 4000. From the daily distribution it can be seen that the average number of vehicles on the weekdays was close to 3000 while on the weekends it was around 2000. This shows almost a 33% decrease in traffic as compared to the weekdays.

The speed of vehicles is also a very important criterion as it is directly related to the emissions produced by the vehicles. In the rush hours, it was mostly stop and go traffic and the vehicle speed was usually lower in comparison to the off-peak time. This can be seen in the Fig. 12 where the vehicle speed in km/h is plotted for the same period and it can be seen the vehicle speed reduces in the traffic hours.

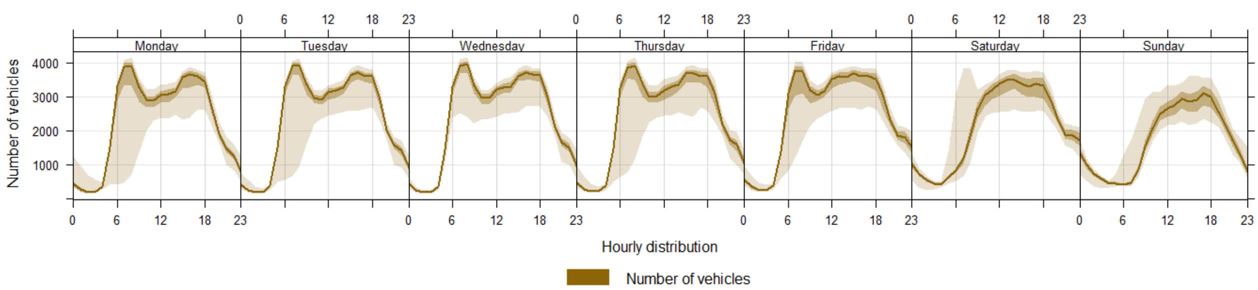


Fig. 11 Hourly distribution of number of vehicles passing by the monitoring station Marienplatz for the period between March 2017 and December 2019.

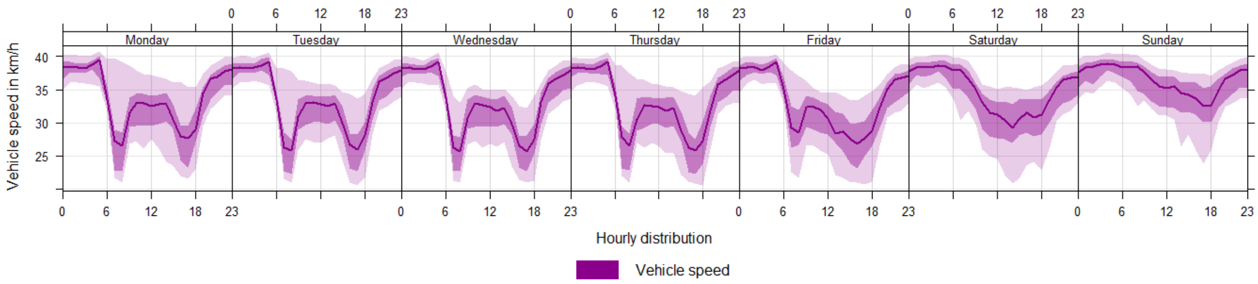


Fig. 12 Hourly distribution of vehicle speed from the vehicles passing by the monitoring station Marienplatz for the period between March 2017 and December 2019.

The pollutant concentration for NO_2 is shown in the Fig. 13 for the period between March 2017 and December 2019. It can be seen that the NO_2 concentration increases with the increase in the number of vehicles as it is the major source of pollutant in the area of investigation. The hourly NO_2 concentration distributions show that the overall concentration was relatively high during the rush hours which was expected due to stop and go traffic in the rush hours. The morning peak is shorter in time for around 2 hours as compared to the evening peak which is extended to around 4 hours. Both morning and evening peaks are quite pronounced with hourly average concentrations reaching as high as above 60 µg/m³ (peak of 95th quantile) for NO_2. It can be seen that the NO_2 concentration was higher on the weekdays than on the weekends. The behaviour of Saturday and Sunday was also different from one another in a way that relatively higher concentrations were measured on Saturday as compared to Sunday.

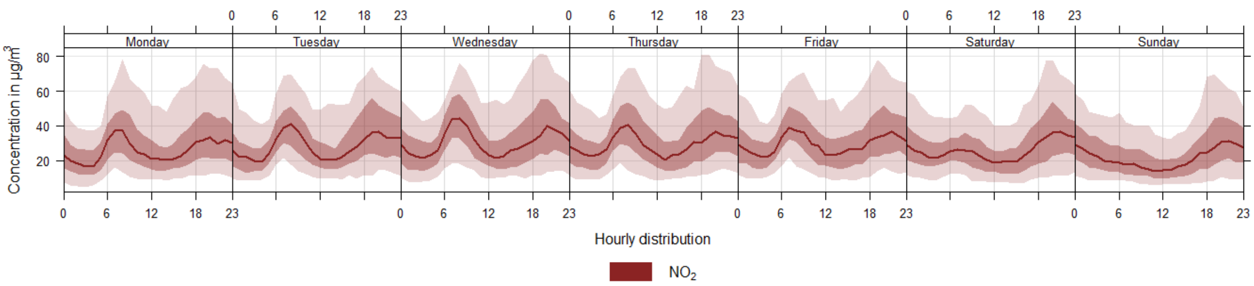


Fig. 13 Hourly concentration distribution of NO_2 for the period between March 2017 and December 2019.

3.3 Seasonal Variation of Different Pollutants

The seasonal variation of different parameters is shown in Fig. 14. For these graphs, daily average values were used to calculate the monthly distribution and an average was taken for each month for the years 2017, 2018 and 2019. For the months of January and February, the averages were taken only for the years 2018 and 2019 as the measurements started in March 2017.

It is interesting to see that most of the pollutants show a seasonal trend. An evident seasonal trend can be seen for O_3 is a product of photochemical reactions for which sunlight is necessary and therefore, its concentration is increased in summer as compared to winter period. The maximum O_3 concentration was measured in the month of June while the minimum O_3 concentration was measured in the month of November. The pollutants CO and BC also show a seasonal trend. An increase in concentration for both CO and BC is measured in the winter season as compared to the summer. An explanation to this increase can be the low temperature in winter because of which more combustion processes and heating is performed which in turn causes to increase the concentration of these two components. A similar kind of trend is observed for the nitrogen oxides as well and it is assumed that the meteorological

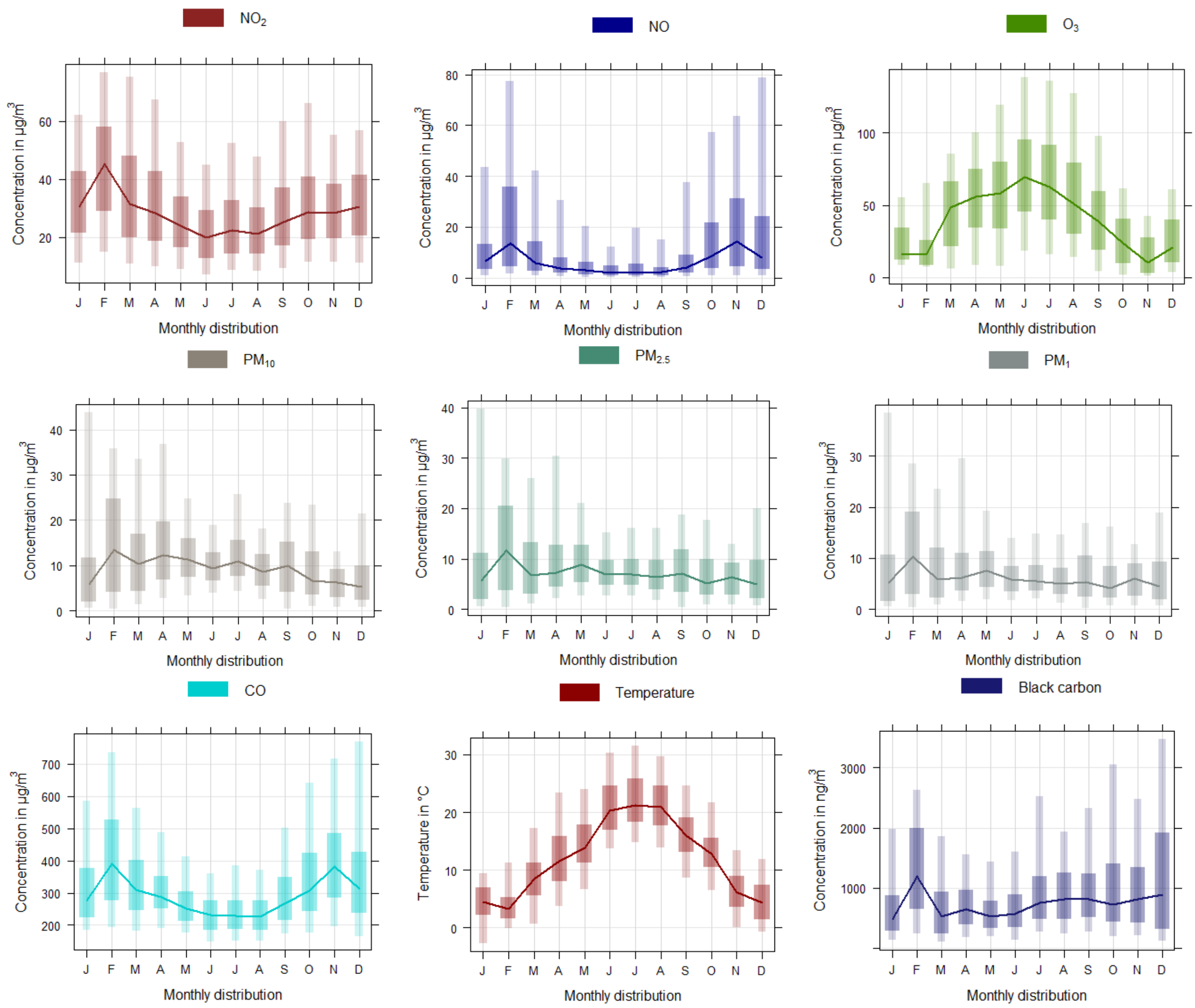


Fig. 14 Seasonal variation of different parameters for the period between March 2017 and December 2019.

conditions can be a reason of this seasonal trend as there are more inversion days in winter as compared to summer, that inhibits the dilution and transport of pollutants when they are emitted and in turn the concentration increases. For the PM there was no specific seasonal variation observed. However, it was seen that the concentration of PM10, PM2.5 and PM1 were not much different from one another showing the fact that particle distribution of the PM measured at this location is mostly fine. The 95th quantile peaks for PM concentrations in the month of January are to be related to new year fireworks.

4. Conclusions

From the results of these measurements, it is concluded that the position of the monitoring station was chosen rightly in order to understand some interesting phenomenon. The wind roses, temperature roses and pollution roses helped to investigate the cold airflows and to find out the direction from where the polluted air comes. The wind rose showed that major wind direction monitored at Marienplatz was southwest with around 75% of the wind blowing from this direction. The temperature rose depicted that relatively warm air was blowing from northwest, northeast and southeast direction towards Marienplatz assuming because of the city traffic and concrete structures. Comparatively colder air was blowing from southwest direction. The cold airflows from west and southwest direction brought cold and fresh air into the city as the temperature of the air coming from this direction was low and less polluted as compared to the air coming from the city side. The pollution roses showed that high concentrations of NO and NO_2 were coming from northeast and southeast directions which are directly dependent on the traffic of the city.

The daily concentration distribution comparison of NO, NO_2 and O_3 concluded that NO and NO_2 concentrations were highest on weekdays and lowest on weekends, especially Sunday, indicating the density of traffic on road on these days. However, O_3 concentration was observed to be highest on Sunday with less O_3 consumption by NO for oxidation to NO_2 and lowest on weekdays.

The meteorological influence on pollutant concentration had a significant effect on the air quality of the area. With the increase in wind speed the pollutant concentration decreased as they were carried away and diluted by wind due to dispersion. In case of O_3, with increase in wind speed, the concentration increased assuming because it is produced in urban areas and is carried towards the city. Wind speed of daily average 1 m/s was measured at Marienplatz for the evaluation period that was moderately low to disperse the pollutants.

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