State of the Environment Report for Malta 2005 - Background Report on Air Quality

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1. Introduction

Since the publication of the last State of the Environment Report in 2002, Malta has become an EU Member State in May 2004, taking on all the obligations and all legislation in relation to air quality. The air quality Acquis, mainly consisting of the Air Quality Framework Directive (1996/62/EC) and its four Daughter Directives, requires member states to comply with limit values for all pollutants regulated under 1996/62/EC within specific timeframes.

The table below lists all pollutants covered by the Framework Directive and the limit value for each pollutant with the relevant averaging period and number of exceedences allowed.

Pollutant	Averaging Period	Limit Value to be met by	Number of Exceedences allowed per year
Sulphur Dioxide	1 hour	350 μg/m^3 by Jan 2005	< 25 times
	24 hours	125μg/m$_3$ by Jan 2005	< 4 times
PM_{10}	24 hours	50 μg/m^3 by Jan 2005 50 μg/m^3 by Jan 2010	< 36 times < 8 times
	1 year	40 μg/m^3 by Jan 2005 20 μg/m^3 by Jan 2010	none
Carbon Monoxide	8 hours	10 mg/m^3 by Jan 2005	none
Nitrogen Dioxide	1 hour	200 μg/m^3 by Jan 2010	< 19 times
	1 year	40 μg/m^3 by Jan 2010	none
Ozone	8 hours	120 μg/m^3 by 2010	< 26 days
Benzene	1 year	5 μg/m^3 by Jan 2010	none
Lead	1 year	0.5 μg/m^3 by Jan 2005 or 2010 depending on the sources	none
Arsenic	1 year	6 ng/m^3	none
Cadmium	1 year	5 ng/m^3	none
Nickel	1 year	20 ng/m^3	none
Polycyclic Aromatic Hydrocarbons (Benzo (a) Pyrene)	1 year	1 ng/m^3	none

The last SoER revealed some issues of concern regarding the quality of air in Malta. In particular the benzene burden, but also suspended particulate matter was found to be very high. Sulphur dioxide downwind and around the Marsa power plant and along main roads was also identified to be high. High levels of ozone were also reported, especially in the less traffic influenced localities in Malta and Gozo.

In addition to the SoER 2002, a preliminary air quality assessment was carried out by AEA Technology Environment (Stacey and Bush, 2002). The bases for their assessment were the diffusion tube measurements made between March 2000 up to May 2001, and temporary real time measurements in various locations between 1999 and 2000 as well as the emissions inventory for Malta, 1997. In this report recommendations were made about where to set up stations for a permanent air quality monitoring program with regards to the different air pollution regimes, e.g. background, suburban, traffic etc.. The realisation of this real time monitoring network consisting of five stations is nearly complete. Presently two of these monitoring stations are in operation, while monitoring using passive diffusion tubes is an ongoing process.

This study concentrates on the present situation and trends of the major pollutants, which were identified to be of concern to the health of the Maltese population. Considerable improvement has been achieved in certain areas, and this report shows that positive results can be achieved with the introduction of abatement measures, albeit with increased costs.

2. The Air Pollution Measurements Analysed in this Study

2.1. Diffusion Tube Network

Since the launching of the National Air Monitoring Programme by the Environment Protection Department in 1999, surveys of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and hydrocarbons such as benzene, toluene, ethylbenzene and xylenes concentration in the air have been performed using diffusion tubes. This passive method comprises of small tubes (7 cm long, 1 cm diameter), which are open at the bottom and contain an absorbent at the base of the lid. The air molecules enter the bottom and diffuse through the tube to the top end where the pollutant is absorbed by the absorbent. The exposed tubes are then analysed in the lab. In principle the results of this simple method should be linear corresponding to the pollutant's average concentration in the air over the exposed period. However, factors such as wind speed, temperature, humidity, exposure time and even the method of preparation can have significant influence on its accuracy (Laxen and Wilson, 2002; Colls, 2002). Another disadvantage of this method is that results are not obtained instantly due to the laboratory work involved. They also give only the average concentration of a pollutant over the exposure period, which makes it difficult to assess the air quality in terms of threshold exceedences. The advantage of this method is that it is relatively inexpensive and simple regarding the handling and can therefore be used to survey large areas.

In this study, diffusion tube measurements from January 2003 until December 2004 were analysed. The tubes were regularly changed about once a month with almost no interruption and sent to a lab in the UK for analysis. Although such measurements were also performed in 2002 the tubes were exposed for too long and were therefore not considered for evaluation.

From January 2003 until February 2004, the diffusion tube network consisted of 124 locations in 31 towns and villages across Malta and Gozo. Most of them were situated in the Southern and Northern harbour districts. However, in order to have a better spatial coverage across the country many of the diffusion tube sites were relocated in March 2004 being now situated in 44 towns and villages. Table 1 gives the code of the localities before and after the restructuring of the network as well as the number of tubes installed for each pollutant. In order to avoid any loss of information by mixing the two data sets with different number of tubes in each locality as well as sometimes different locations, annual averages were calculated using the measurements from January 2003 until February 2004 and shall be defined as the investigation year 2003, while the measurements from March 2004 until December 2004 shall be referred to as the investigation year 2004.

As listed in Table 1, several diffusion tubes were installed in each of the towns and villages at sites, which can be considered to be representative as "roadside", "urban intermediate" and "urban background". One has to bear in mind that great differences in the presence and behaviour of air pollutants can occur between individual sites although located relatively close to each other. Such differences can mainly be attributed to factors such as traffic patterns or the vicinity to other pollution sources (garages, workshops, building sites, petrol stations etc.), the topography (valley or hillside), the density and heights of buildings and the meteorological parameters of which most important is the wind direction and wind speed.

	Code	Jan. 2003 – Feb. 2004	Mar. – Dec. 2004
Valletta	VLT	4	2
Floriana	FL	4	2
Pieta	PT	4	3
Hamrun	HMR	4	3
Marsa	MRS	4	4
Cospicua	COT	4	4
Paola	PLA	4	3
Fgura	FGR	4	3
Zabbar	ZBR	4	3
M'Skala	MSK		3
Gudja	GDJ	4	3
Luqa	LQA	4	3
Zejtun	ZTN	4	3
B'Bugia	BBG	4	3
M'Xlokk	MXL	4	3
Attard	ATT		2
Balzan	BZN		2
Lija	LJA		2
Naxxar	NXR		3
B'Kara	BKR	4	4
Qormi	QRM	4	3
Mosta	MST	4	3
Mgarr Malta	MGM		3
Bugibba	BUB		6
Zebbug	ZBG		3
Siggiewi	SGG	4	4
Zurrieq	ZRQ		3
Mqabba	MQB		2
Qrendi	QRD		2
Sliema	SLM	4	2
Swieqi	SWQ	4	5
Msida	MSD	4	2
San Gwann	SGN	4	3
Gzira	GZR	4	3
Mellieha	MLH	4	3
Dingli	DGL	4	3
Rabat	RBT	4	3
Ghajn Tuffieha	GHT	4	
Mgarr Gozo	MGR	4	3
Victoria	VCT	4	3
Xlendi	XLD	4	2
Marsalforn	MSL	4	3
Gharb	ARB		2
Xewkija	XKA		2

Table 1:
The code of localities and the corresponding number of diffusion tubes installed for each pollutant before and after their relocation, from January 2003 to February 2004 and from March to December 2004, respectively.

Figure 1 shows as an extreme example the factor by which the diffusion tube measurements of sulphur dioxide, nitrogen dioxide and benzene at two sites in Floriana, namely St. Anne Street and Market Street, differ from each other. The two sites are only about 200 meters away from each other, but show great differences in the concentrations of pollutants measured. Clearly, St. Anne Street being a dual lane road both ways with a permanently high amount of vehicles passing through throughout the day is more influenced by vehicle emissions than the side street, Market Street. The high buildings in St. Anne Street create also a so-called street canyon, which reduces the dispersion of pollutants particularly on calm days. Extreme months of the evaluated time period show that the SO_2 mixing-ratio in St. Anne Street can be about 4 times higher, NO_2 about 5.6 times higher and benzene up to 6 times higher than the ones in Market Street.

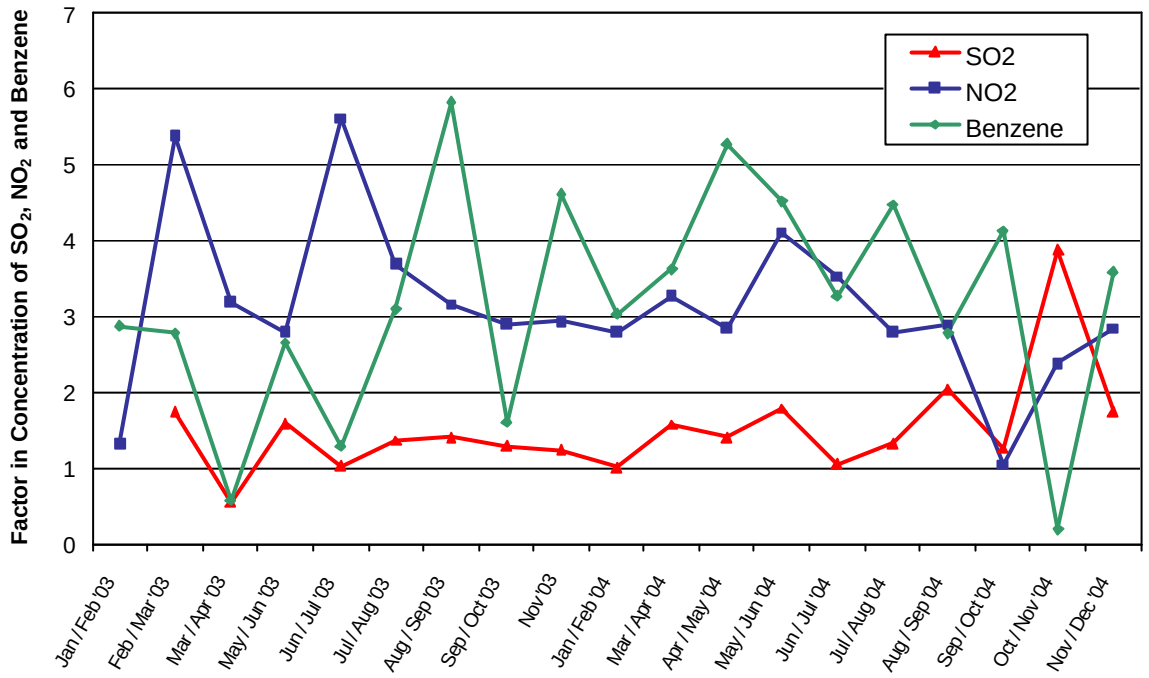


Figure 1:
The factor, by which the SO_2, NO_2 and benzene concentrations measured in St. Anne Street differs from the ones measured in Market Street).

However, in order to obtain a more homogeneous picture regarding which localities are the most affected by air pollutants, averages were calculated from the diffusion tube sites in each locality. Diffusion tube measurements can only give long-term averages and are therefore not suitable to assess short-term effects of air pollutants.

2.2. Real Time Monitoring

More or less continuous real time measurements have been carried out by the Malta Environment and Planning Authority (MEPA) in Floriana / St. Francis Ravelin since October 2003 using various types of analytical instruments, described by Callus (2000). These instruments are regarded as standard reference methods by the European standards making body CEN. The pollutants measured there are sulphur dioxide, nitrogen monoxide (NO),

nitrogen dioxide, carbon monoxide (CO), ozone, benzene and particulate matter of aerodynamic diameter equal to 10µm (PM_{10}). Table 2 shows the availability of measurements in days for each pollutant and month.

	O_3	SO_2	NO	NO_2	CO	Benzene	PM_{10}
Oct '03	9	16	16	16	16		
Nov '03		23	23	23			
Dec '03	*	31	31	*	30		
Jan '04	27	29	29	*	29	*	
Feb '04	19	25	25	25	20	*	
Mar '04	23	18	24	23		*	
Apr '04	30	30	30	30		*	
May '04	31	30	30	30		*	
Jun '04	30	30	30	30	13	19	
Jul '04	22	25	*	*	*	30	*
Aug '04	30		*	*		28	*
Sep '04	30	15	15	15	15	30	15
Oct '04	26	30	30	30	30	13	30
Nov '04	30	30	30	30	30	26	30
Dec '04	31	31	31	31	31	31	24

Table 2:
Data availability of real time measurements in days at Floriana. The asterisk indicates that although measurements are available these were not considered due to technical problems.

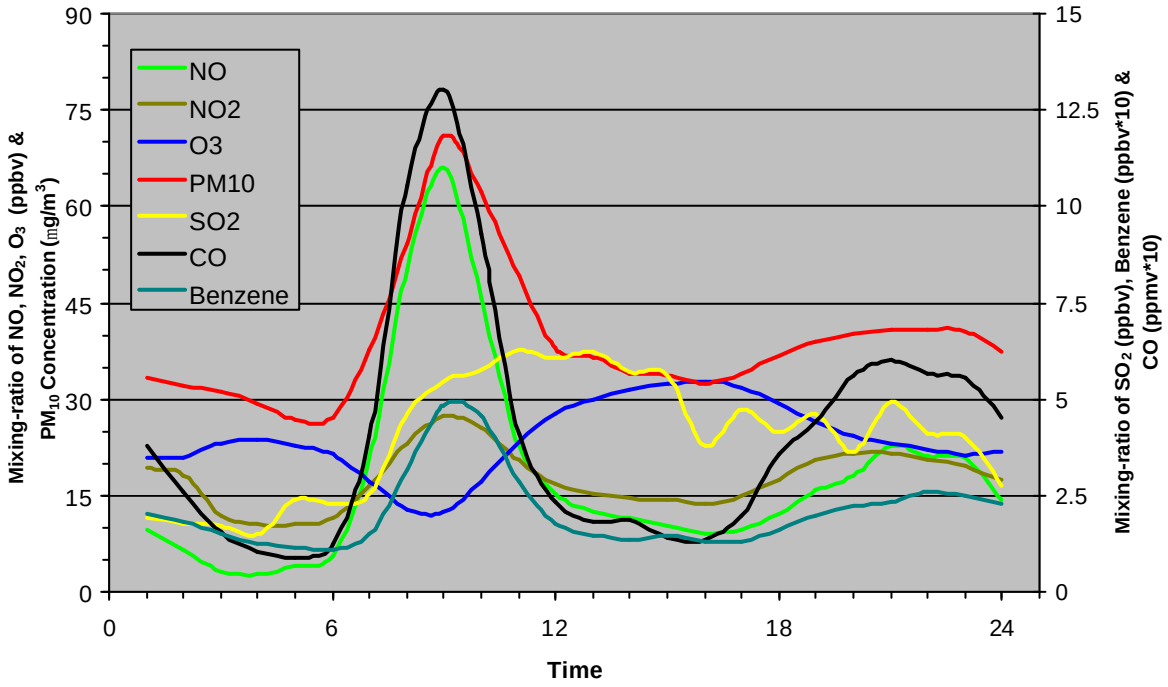


Figure 2:
Diurnal variation of trace gases and PM_{10} measured in Floriana from mid September until end of December.

This station is by design, strongly influenced by traffic due to its closeness to National Road, the continuation of St. Anne Street (see chapter 2.1.). However, a comparison of this real time monitoring site with the other two diffusion tube sites in Floriana reveals that the overall levels of air pollutants there are more similar to the ones in Market Street (e.g. maximum difference of NO_2 was 5 ppbv) rather than St. Anne Street. This may be due to the immediate surrounding at St. Francis Ravelin, which is more open regarding building density allowing an easier dispersion of air pollution.

Figure 2 shows the diurnal variation of the trace gases and particulates measured there from mid September until the end of December 2004. These individual gases will be discussed in detail in the following chapters. However, the obvious characteristic of the measurements at this site is that classic air pollutants originating from traffic, namely NO, NO_2, CO, benzene and also particulates, show a clear correlation. A strong concentration peak of these air pollutants is observed at around 09:00 hour during the morning rush-hour, while the evening rush-hour seems to be more dispersed over a longer period starting from 17:00 hour. This characteristic of the diurnal pattern of traffic emissions was also observed at other localities e.g. in Xewkija (for CO and O_3; Nolle, 2001). The variation of SO_2 concentrations does somewhat differ to what is expected at first and will be discussed in chapter 3.1. The ozone concentrations are anti-correlated to that of NO as is commonly observed at such sites and this will be also discussed in detail in chapter 3.4.

Real time measurements of some air pollutants also started in July 2004 from the premises of the Pollution Control Waste and Minerals Unit of MEPA, at Corradino Industrial Estate / Paola. This station was set up in accordance to the recommendations made in the AEAT report (Stacey and Bush, 2002) as a location of maximum ground level concentration arising from the Marsa power plant emissions. The instruments installed at this site are the ones, which were used in the mobile unit in previous years and extensive maintenance work was necessary. A detailed analysis of this data has also not been possible so far due to lack of human resources.

Continuous measurements in particular of ozone (since 1997), but also of carbon monoxide and sulphur dioxide have been performed at Gordan lighthouse / Gozo by the University of Malta / Physics Department. This station on a hilltop in the very North-west of Gozo can be considered as one of the least influenced sites by local pollution sources on the Maltese islands. Measurements there are therefore of particular interest regarding how much of the air pollution burden in Malta is "imported" through transboundary pollution transport processes.

3. Results and Discussion

3.1. Sulphur Dioxide

Sulphur dioxide is a highly soluble, colourless gas with a pungent smell in high concentrations. Natural sources of SO_2 are the direct emissions from volcanoes, the oxidation of dimethyl sulphide (DMS) formed as a metabolic product by marine phytoplankton and the oxidation of hydrogen sulphide (H_2S) produced by vegetation and from decaying processes in soils by bacteria. These natural sources are believed to contribute to about a quarter of the global sulphur content in the air. However, the majority of sulphur emitted into the atmosphere is of anthropogenic origin in form of SO_2, which attributes to about three quarter of the global emissions (Colls, 2002). The combustion of fossil fuel for the energy generation accounts for most of it besides biomass burning and road transport.

Ultimately, SO_2 in the air will be further converted either into sulphate ions or to sulphuric acid. The latter may lead to an increased erosion effect of the Maltese limestone buildings.

When entering the respiratory airways SO_2 is efficiently deposited in the mucous membranes that line the nose and the upper respiratory tract. This is due to the fact that SO_2 is highly water soluble. At ambient air concentrations the acidity can be buffered by the mucus. However, this buffering characteristic is reduced in the acidic saturated mucus typically found in asthmatics. Very high concentrations in SO_2 will lead to decrease in lung functions (e.g. as the forced expiratory volume; FEV) and the increase in airway resistance with symptoms such as wheezing, cough and shortness of breath. Long-term exposure to SO_2 may lead to bronchitis.

However, SO_2 gas by itself is not particularly toxic and its effect on health within the urban air has to be seen in connection with the presence of other pollutants mainly sulphuric acid aerosols and smoke particulates. Particulates are deposited much more efficiently in the airways of the deeper lung. This synergy of air pollutants led to the high mortality rate associated with the well known smog (smoke + fog) episodes, e.g. the ones in London in the 1950s and 1960s.

SO_2 affects plants directly in gaseous form but also as sulphuric acid droplets form with water vapour in the air. Low concentrations in SO_2 can actually have a fertilising effect on plants in case of limited sulphur supply through the roots. However, an exposure of plants to SO_2 at concentrations levels often found in ambient air and in particular within the vicinity of emission sources leads to the breakdown of chlorophyll and eventually to the death of plant tissue. The response of foliage to SO_2 exposure depends on many factors such as plant species, age, concentration, duration and frequency and is commonly observed as colour change in marginal and interveinal necrotic areas of the leaves. Acid wet deposition of sulphuric acid also causes injuries to the foliage creating strains reflecting the outline of the droplets.

The EU Air Quality Directive (1999/30/EC) for SO_2 gives following thresholds:

- 350 µg/m^3 hourly limit value for human health protection not to be exceeded more than 24 times per year.
- 125 µg/m^3 daily limit value for human health protection not to be exceeded more than 3 times per year.
- 20 µg/m^3 annual limit value for ecosystem protection.

The WHO recommends an annual limit value of 50 µg/m^3 for human health protection.

Table 3 gives the exceedences of these limit values at the real time station in Floriana. The hourly limit value of 350 µg/m^3 was in all exceeded 81 times during the period from October 2003 until December 2004. Considering the year 2004 only this value was exceeded 61 times. Also the 24 hour limit value was exceeded 11 times for the entire period available and 9 times in 2004 only. The SO_2 burden, at least at this locality, was well above to what is required by EU standards.

	hourly, 350 µg/m^3	**daily, 125 µg/m^3**
Oct 03	4	0
Nov 03	2	0
Dec 03	14	2
Jan 04	6	1
Feb 04	33	5
Mar 04	0	0
Apr 04	15	2
May 04	1	0
Jun 04	0	0
Jul 04	0	0
Aug 04	n/a	n/a
Sep 04	0	0
Oct 04	0	0
Nov 04	1	0
Dec 04	5	1
Sum	**81**	**11**

Table 3:
The exceedences of the hourly and daily thresholds for SO_2 at the real time Floriana station.

Table 3 above shows a considerable difference in the number of hourly exceedences between January 2004-April 2004 and May 2004-December 2004 (54 as compared to 7). This difference may be attributed to the introduction of low sulphur fuel. However, seasonal differences in the pollution dispersion characteristics of the atmosphere may also play a significant role to this difference. Further investigation would be necessary.

Local SO_2 sources on the Maltese islands can be specified as the power plants in Marsa and Delimara as well as the traffic in particular from diesel vehicles. The boilers of Marsa power plant are operated with heavy fuel, which used to have a sulphur content of about 2.5 to 3% before Enemalta made the switch to more expensive low-sulphur fuel in April 2004. The low sulphur fuel, which is being used now, has a sulphur content of less than 1% (deJonge, 2004; Pace, 2004). The Delimara power plant is being operated to about 50% with heavy fuel and 50% with diesel oil. The latter has a sulphur content of less than 0.2% (typically around 0.1%) since November 2003.

Unleaded petrol and leaded replacement petrol (LRP), the latter introduced in January 2003, are virtually sulphur free (Pace, 2004). Hence, the sulphur dioxide emission derived from road transport can mainly be attributed to be from diesel vehicles. However, the sulphur content of diesel imported for transportation was gradually reduced by Enemalta during the period from September 2000 and January 2002. According to the National Statistics Office of Malta diesel had a sulphur content of 0.5% before, but was replaced by one with a 0.2% content in

September 2000. A further reduction to 0.055% occurred in February 2001. Finally, since January 2002 diesel contains only 0.035% sulphur.

However, the fact that the diurnal pattern of sulphur dioxide measured in Floriana (Figure 2) does not follow the same pattern as that of the other trace gases (apart from ozone) may lead to the conclusion that emissions from private diesel cars, which result from the traffic flow during the rush-hours, do not have a particular impact. Further investigation on this subject is needed.

Another source of air pollutants in Malta, which is often forgotten when discussing local air pollution sources, is air traffic. Emissions from aircraft might not only affect in particular the villages around Malta International Airport, but also the entire island since aeroplanes easily pass over the area of the Maltese islands when landing and taking off. According to the NSO (2004a) about 27000 aircraft movements per year took place in the last three years. There are on average about 75 movements per day with an average of about 96 passengers on board of each flight. The amount of air traffic is obviously strongly coupled to the tourist season (see also chapter 3.2. and Figure 11). Jet fuel has a sulphur content of about 0.3 % and about 25% of Enemalta's sales comprises that of aviation fuels. Certainly, most of the total fuel an aeroplane usually carries is used while cruising and emissions are therefore spread along a long distance. However, the relative fuel consumption is much higher during takeoff and landing. To get an idea, aeroplanes such as those used by Airmalta consume approximately 1.2 tons per hour of fuel while cruising, but need about 2 tons in 15 minutes to climb to an altitude of 5000 m. Thus, most of the emission during takeoff maybe still take place at a height low enough to affect the population on the ground directly, especially during the summertime when strong convection prevails. However, the fuel consumption depends strongly on the actual load as for any transport system.

Figure 3 shows the annual averages of SO_2 of the diffusion tube data for the investigation years 2000 (taken from Vella et al. 2002) 2003 and 2004 for each locality. Figure 4 also shows the annual averages of SO_2 for the years 2003 and 2004 only in the form of a bubble chart. The diameter of each bubble corresponds to the SO_2 concentration as depicted in Figure 3. The bubbles are additionally colour coded and divided into three ranges; smaller than 15 $\mu g/m^3$, between 15 $\mu g/m^3$ and 30 $\mu g/m^3$ and greater than 30 $\mu g/m^3$.

As one can see in Figure 3, SO_2 concentrations published in the SoER 2002 (Vella et al., 2002) were higher in almost all localities compared to the ones from the year 2003. Another substantial decrease is evident also in almost all localities from the year 2003 to 2004.

Being close to the Marsa power plant, higher SO_2 concentrations were recorded in Fgura, Paola and Marsa in 2003. As an average from several diffusion tube measurements made in each locality none of them exceeded the annual limit value of 50 $\mu g/m^3$ for human protection. However, analysing each site separately, then this value was exceeded in Fgura / Hompesch Road with 61 $\mu g/m^3$. This site is also situated in a main road and therefore influenced by both the power plant and traffic.

In 2004, a drastic drop in SO_2 concentrations was observed e.g. in Luqa (51%), in Fgura (48%), in Zejtun (44%), in Gudja (40%), in Birzebbuga (40%), in Paola (39%) and in Marsa (23%). The nationwide reduction was 36%. This is very likely due to the fact that low sulphur fuel was introduced in the beginning of that year, since the greatest changes were recorded in localities, which fall in line with the main wind direction from west-north-west. In 2004, the

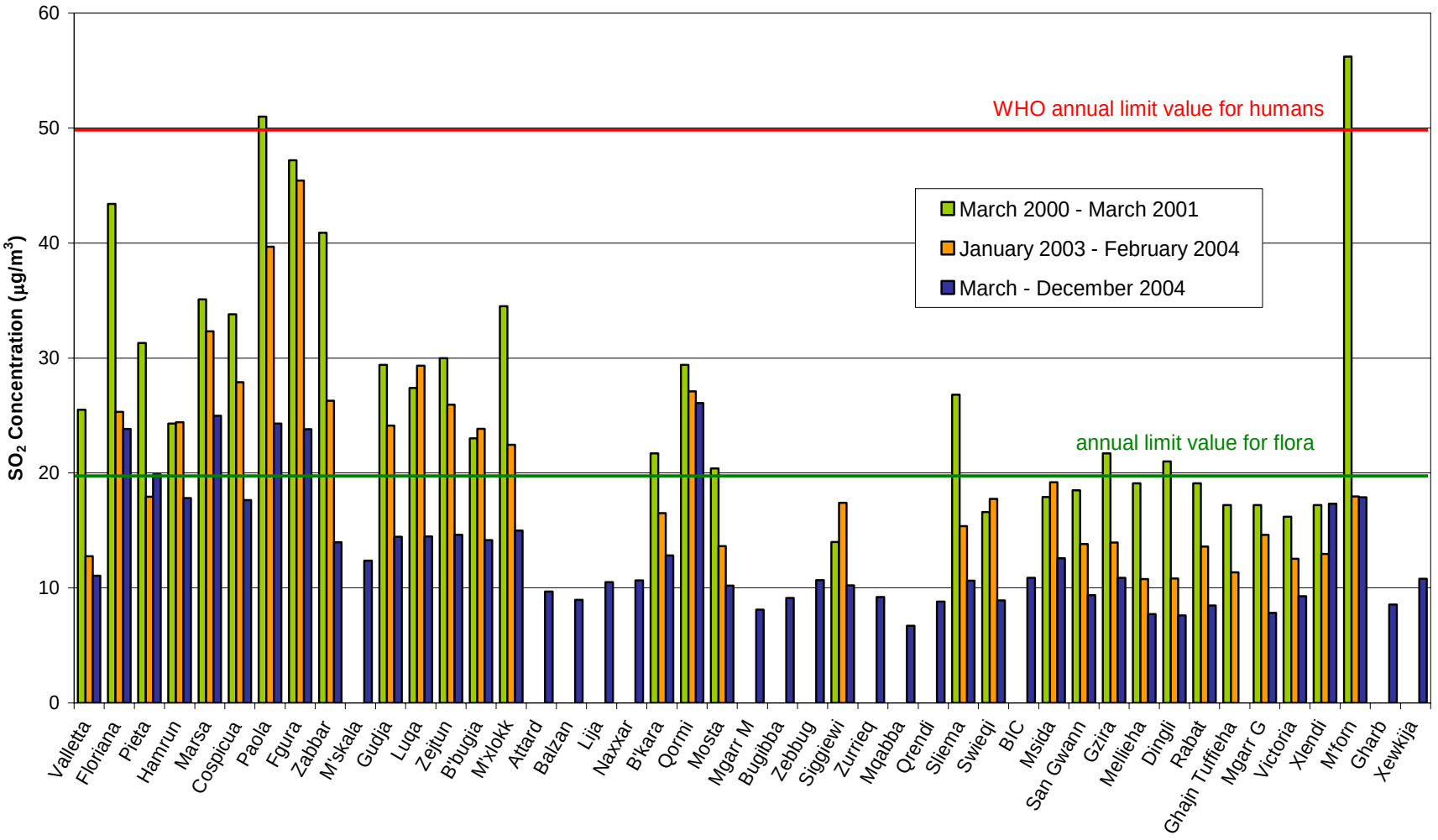


Figure 3:
Annual averages of SO_2 diffusion tube measurement for the investigation years 2000, 2003 and 2004.

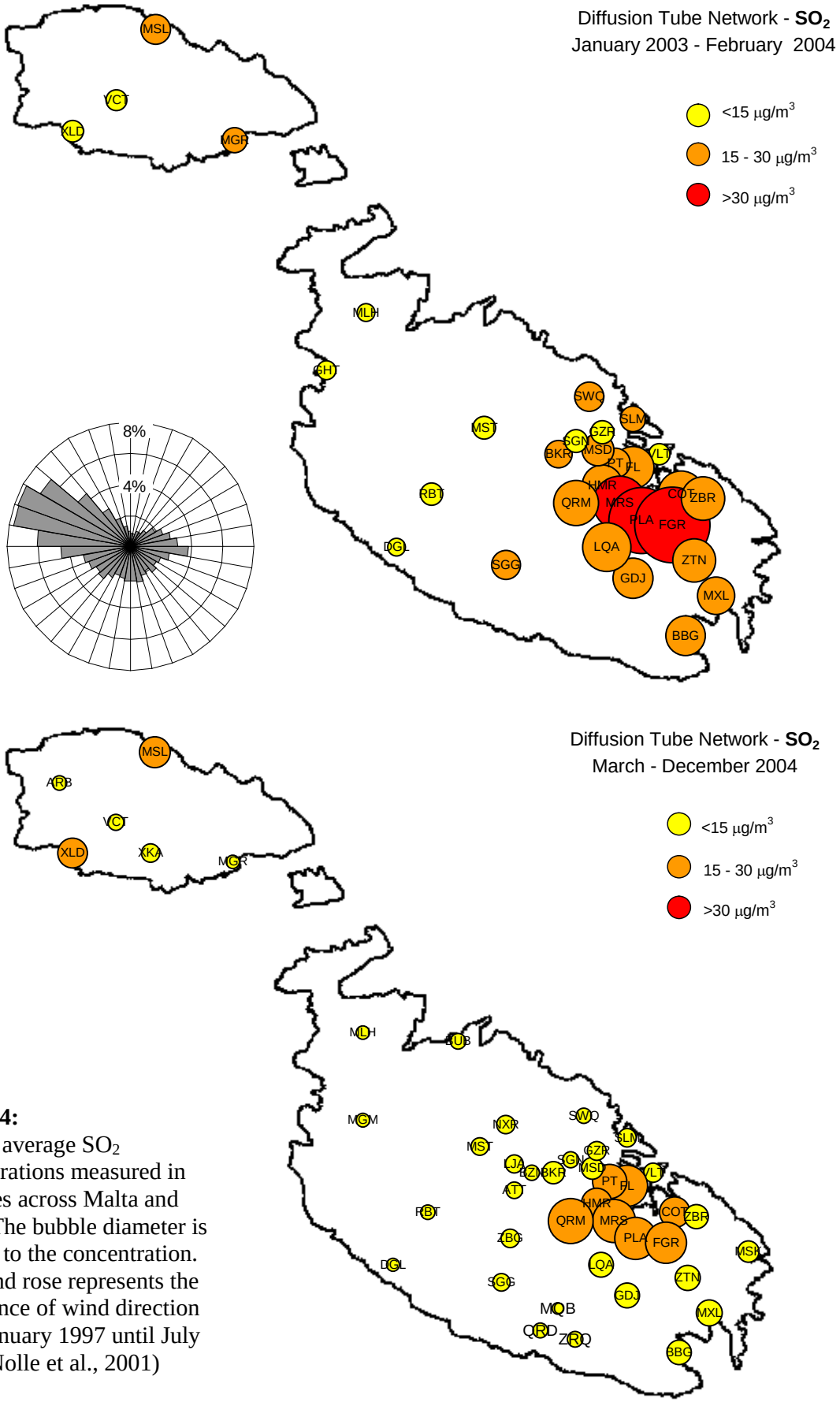


Figure 4:
Annual average SO_2 concentrations measured in localities across Malta and Gozo. The bubble diameter is relative to the concentration. The wind rose represents the occurrence of wind direction from January 1997 until July 2001 (Nolle et al., 2001)

highest annual average of SO_2 concentration for a locality was recorded in Qormi, which is also closely situated of the Marsa power plant. The highest value for individual sites was recorded in Marsa / Spencer Hill with 37 µg/m^3.

Vella et al. (2002) also reported an anomaly of a very high SO_2 value in Marsalforn, which was in fact above the 50 µg/m^3 limit value. Figure 2 and 3 clearly show that the SO_2 burden in Marsalforn is still relative high compared to other villages around Malta and Gozo (except for Xlendi in 2004), which are not near the power plants or along main roads. Figure 5 shows the histogram of SO_2 measured in Marsalforn for the last two years. In 2003, high values were recorded in March / April and July / August. Since Marsalforn is a popular resort among the Maltese population this might have been a result of increased traffic during the periods around Easter and the feast of Santa Marija. On the other hand, NO_2 and benzene concentrations, both mainly derived from traffic, are actually among the lowest in 2004 (see chapter 3.2. and 3.3.). The impact of private diesel cars may also be neglected as discussed above. Furthermore, this pattern is not visible in 2004, when the SO_2 concentration peaked in May / June and gradually declined until the end of the year. Another possible source of SO_2 near Marsalforn may be identified as the dumping site a few hundred meters up the hill in the outskirts north of Xaghra now being used as waste transfer facility. When east winds prevail, Marsalforn is often affected by odour and smoke advected from this site. The location of the diffusion tubes at Marsalforn are quite near to a sewage pumping station, and emissions of Hydrogen Sulphide from the station could be a reason for the increased levels of SO2. Hydrogen sulphide formed through decay processes becomes quickly oxidised to SO_2. The relation with the peak holiday periods around Easter and Santa Maria, and increased sewage flows, seem to indicate this probability. However, further investigations are necessary to come to a conclusive explanation.

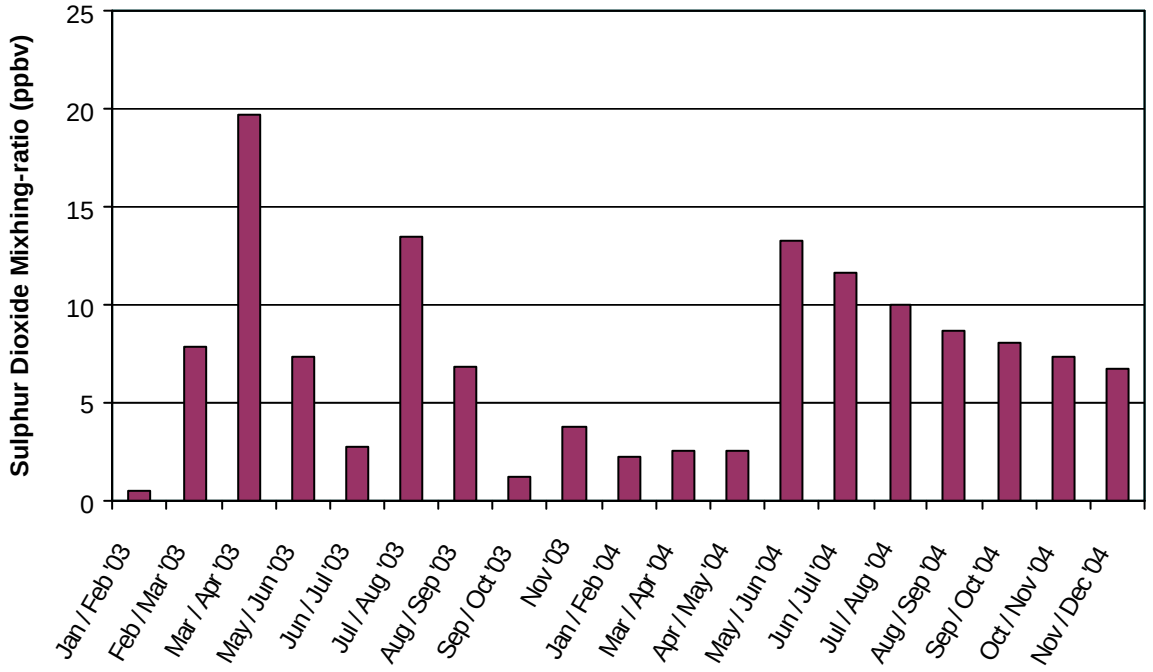


Figure 5:
SO_2 diffusion tube measurements in Marsalforn.

Figure 6 shows the evolution of the sulphur dioxide concentration of selected localities, which are likely to be most effected by emissions from the power plants, namely Qormi, Fgura, Paola, Marsa, Zejtun, Luqa and Marsaxlokk. Compared to this the nationwide averages as well as the averages of the remaining localities (apart from these selected six) are also depicted. To avoid a distortion of the result when calculating the nationwide averages and the one for the remaining localities only those localities were considered in which measurements were made during the entire two years period. Since the diffusion tube network consists of more sites in a cleaner environment after its reorganisation an unselective calculation of the average would result in a general lower pollutant concentration and would therefore be misleading. Instead the measurements in Ghajn Tuffieha in 2003, the ones made in Mgarr / Malta were taken instead for the investigation year 2004.

Figure 6 clearly shows that the difference between the SO_2 burden in towns and villages (obviously more affected by the power plants) and the remaining ones decreased significantly. However, the figure also shows a clear maximum of sulphur dioxide levels on the Maltese island in summer, which is opposite to what is observed even at rural stations on the continents in the northern hemisphere (Warneck, 2000). The maximum there is usually found during the winter months due to increased emissions for heating with coal and oil.

Several factors may contribute to the seasonal pattern of SO_2 observed in Malta. A small contribution may come from the oxidation of Dimethyl sulphide (DMS) produced by marine phytoplankton (Bardouki, 2003), which may be most productive during the early summer months.

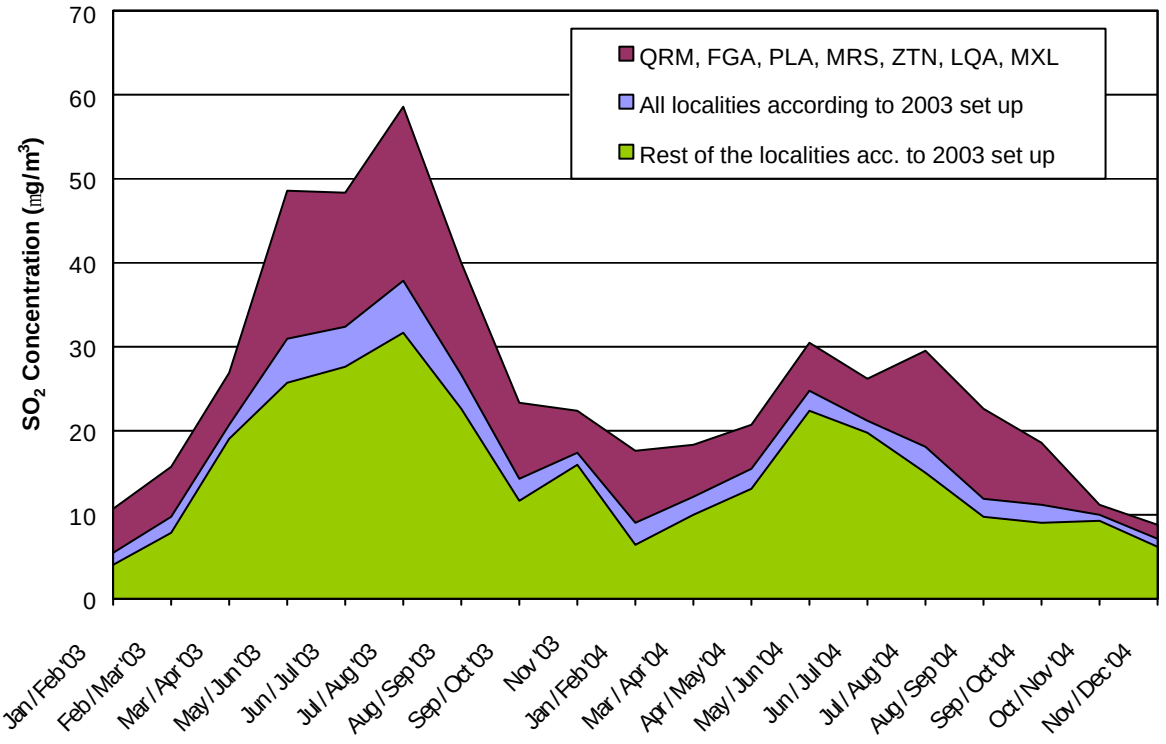


Figure 6:
Temporal development of averages of SO_2 concentration for selected localities, the remaining ones and nationwide. Only those localities, in which measurements were made during the entire time period, were considered.

Figure 7 shows the total energy generated by Enemalta (NSO, 2004b) for selected averaging periods and for the years 2003 and 2004, separately. Two maxima, one in winter and one in mid-summer are evident, which lead to the conclusion that the amount of sulphur emitted by the power plants alone may not be responsible for the seasonal variation of SO_2. However, in recent years the maximum energy consumption by the Maltese population changed from the winter months (used for heating) to the summer months (used for cooling) because of affordable air conditioning systems now available. The energy produced in the summer of 2003 was also clearly higher compared to the four year average from 1999 to 2002. One also has to consider the fact that total energy consumption is steadily increasing and almost doubled since 1990, which diminishes the efforts by Enemalta to decrease the total sulphur emission in general.

The greater influx of tourists during summer might also account for a certain percentage to the summer SO_2 maximum due to more movements of vehicles (self driven cars and coaches) as well as of aeroplanes and cruise liners. Statistics show that there are approximately 180000 tourists departing from Malta in August compared to about 40000 in January (numbers for 2004; NOS, 2005b), (see also Figure 11).

Another possibility, which has to be considered in order to understand this seasonal behaviour of SO_2 is the influence of transboundary pollution import through medium and long-range transport. The meteorological situation, which prevails in summer, favours the influx of air pollution into the Mediterranean basin from the surrounding countries. Besides the more obvious sources such as e.g. the "nearby" refineries in Sicily, air pollution is transported from many East European countries into the Mediterranean basin during summer, while their emissions are carried eastwards during the winter months. In addition, air pollution is injected into the middle troposphere from the Eastern U.S.A, is then carried towards Europe and

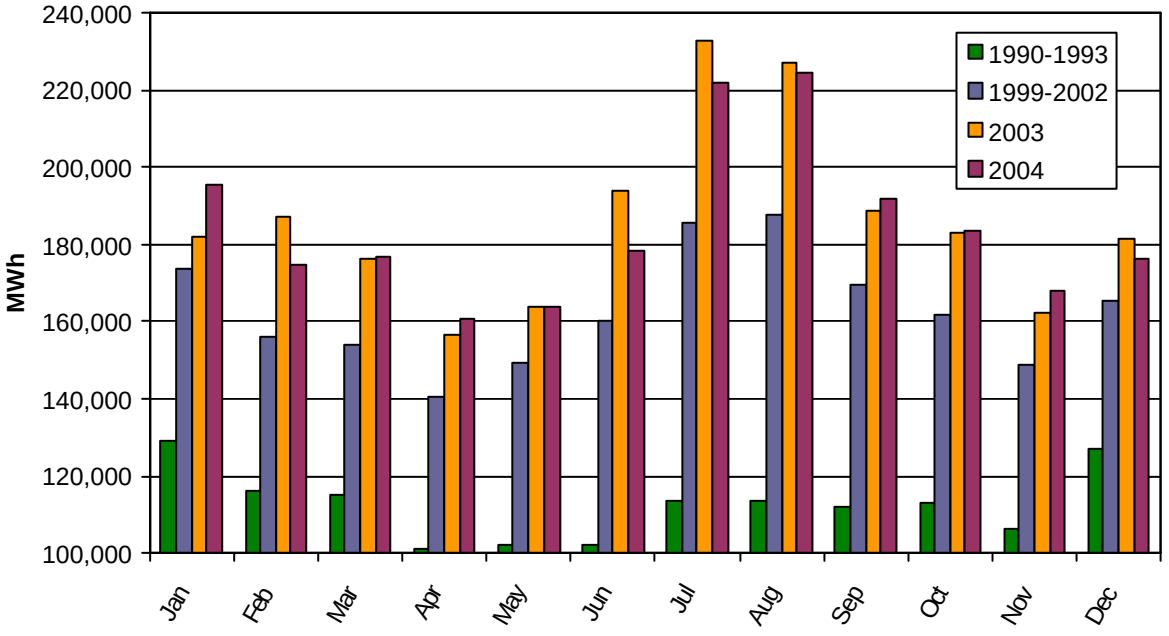


Figure 7:
Seasonal variation of total energy generated on Malta (values taken from NSO, 2004b).

descends over the Mediterranean (Lelieveld et al., 2002). Transboundary air pollution is also an important factor regarding the O_3 concentrations on the Maltese islands and is discussed further in chapter 3.4.

Another important emission source, which is likely to have a significant impact on Malta's air pollution burden is international shipping. The route through the Strait of Sicily and the Malta Channel is one of the world's busiest marine traffic routes and about 30% of all the goods carried on ocean going ships is passing through this area. There are basically no international measures to regulate the emissions from ships as yet (Proposal for a Directive on the sulphur content of marine fuels, and Annex 6 of the MARPOL Convention, which is not yet into force). The engines of cargo vessels are huge (several Megawatt equivalent) and usually operate with heavy fuel oil having a much higher sulphur content (2.7%) compared to the diesel for road transportation. Compared to trucks, ships emit about 30 to 50 time more sulphur per ton and kilometre, twice as much NO_x and about 30 times more polycyclic aromatic hydrocarbons, which are carcinogenic. With a growth rate of 3% in marine traffic it is thought that sulphur emissions in European waters will be equal to the ones on land by 2015 (EEB, 2004). A study carried out by EMEP (Jonson et al., 2000) estimates that approximately 16% of sulphur and about 38% of NO_x (chapter 3.3.) deposited in Malta originates from ships. Although no information is available about the seasonal variability of marine traffic in the Mediterranean it is plausible that ship emissions accumulate easier during the summer months in addition to the other sources discussed above, since there is basically no wet deposition due to the absence of rain.

3.2. Nitrogen Oxides

Oxides of nitrogen in the urban atmosphere are usually found in the form of NO and NO_2, which permanently interact with each other and other pollutants such as ozone and hydrocarbons NO is quickly oxidised to NO_2, while NO_2 is subject to continuous photodissociation until a chemical balance is reached. One very important reaction in which NO is converted to NO_2 happens with O_3. This reaction is also the reason why NO and O_3 are anti-correlated as seen in Figure 2. The concentration of NO and NO_2 is often mentioned as a sum of both being referred to as NO_x. Direct natural sources of NO_x are lightning, the oxidation of ammonia (NH_3) and the flux from the stratosphere, where nitrous oxide (N_2O) is photodissociated. However, the majority of NO_x is produced through combustion processes. This is not only due to the fact that the fuel contains nitrogen but it is rather the nitrogen in the air, which is also oxidised during the combustion process. About 90% of the combustion NO_x emissions occur as NO and one can say that the higher the combustion temperature the more NO is formed. Road traffic is therefore the strongest source of NO_x. Statistics show that there are now about 1.5 persons for each privately owned car in Malta. New cars need to be equipped with a catalytic converter in order to fulfil the requirements outlined in 70/220/EEC, which limits the emissions of CO, NO_x VOCs and PM and which came into force on Malta in November 2002. However, only since January 2005, the exhaust emission test is subject to fail a vehicle undergoing the Vehicle Roadworthiness Test (VRT). These measures should either improve or at least stabilise the situation regarding pollution originating from traffic.

While NO is often considered to be innocuous, it is more and more recognised to be an important agent for cell signalling and therefore cell function in mammals and plants. High concentration in NO_2 is associated with irritation of the mucosa and may lead to irreversible changes of the respiratory system. However, there are indications that the effects of NO_2 on

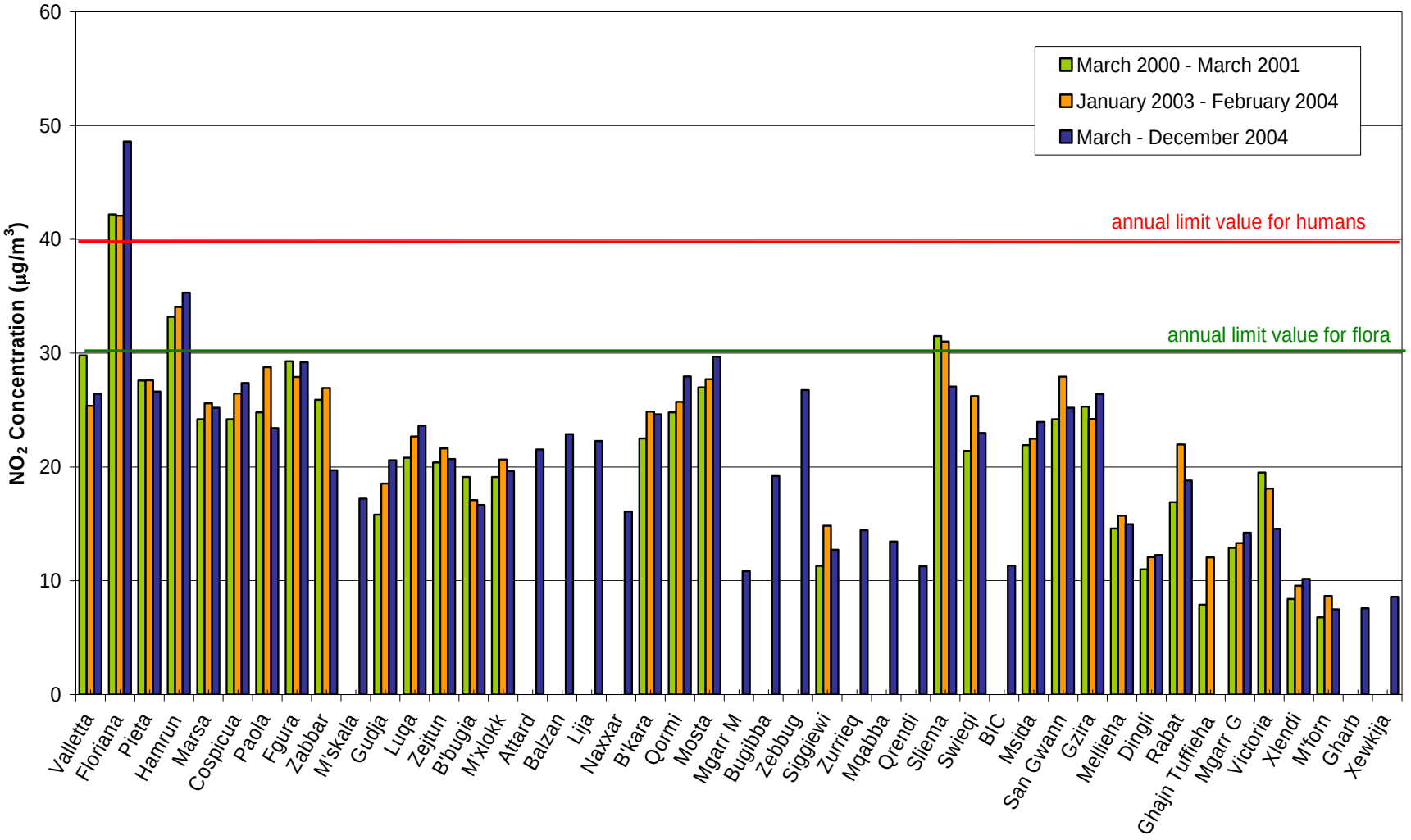


Figure 8:
Annual averages of NO_2 diffusion tube measurement for the investigation years 2000, 2003 and 2004.

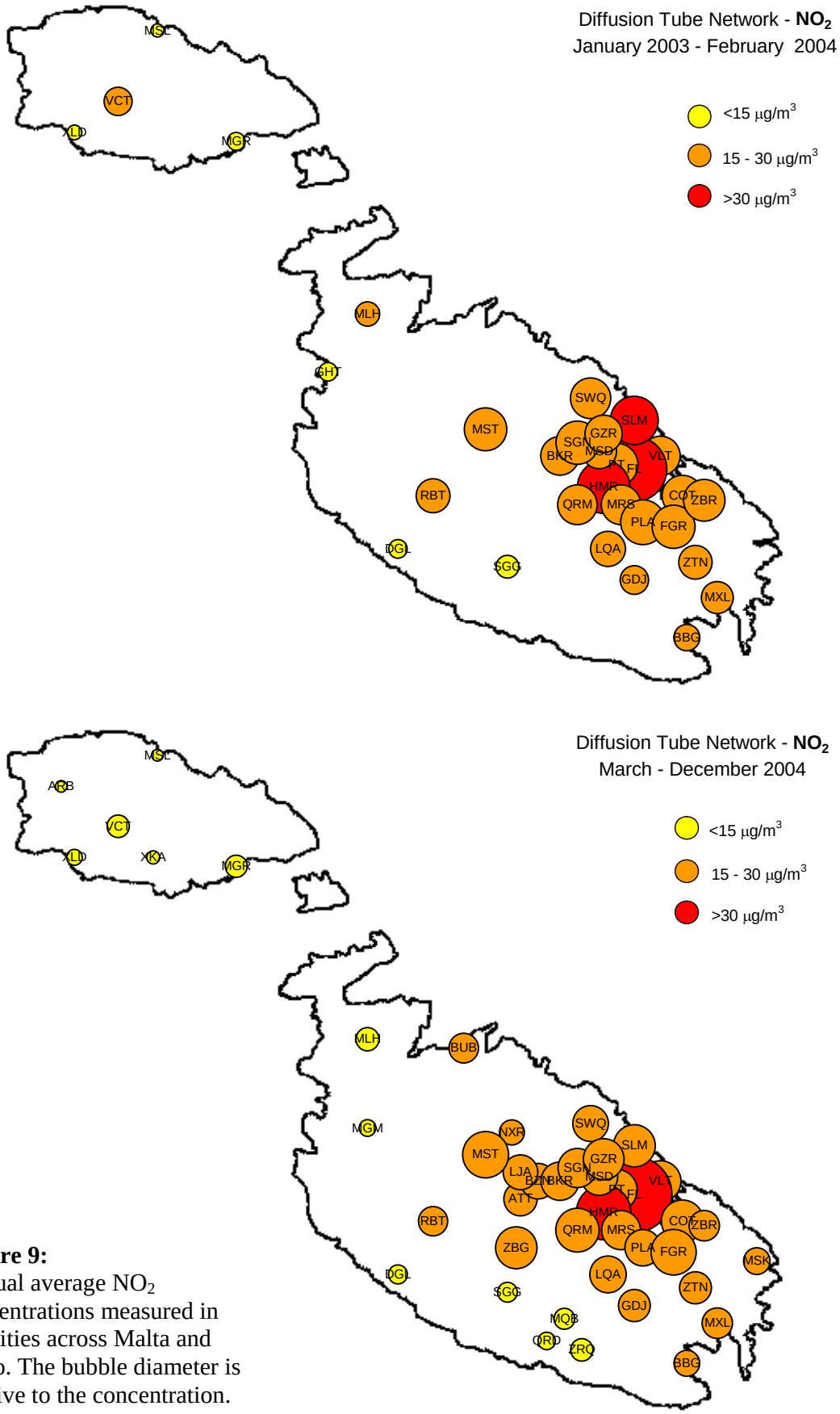


Figure 9:
Annual average NO_2 concentrations measured in localities across Malta and Gozo. The bubble diameter is relative to the concentration.

human health have to be seen in an indirect way. NO_2 seems to promote bacterial infections in the lung in particular in children. There also seems to be enough evidence that nitrated proteins (e.g. found in pollens) formed in polluted air are related to stronger allergic reactions. It therefore appears that asthmatics experience symptoms more likely when exposed to NO_2 and allergens at the same time.

The damaging effects of NO_2 on plants are complex and have to be seen in context with other pollutants present in the air. Thus, when present in low concentrations NO_2 actually acts as a fertiliser and is taken up through the stomata of leaves and actually enhances the plant growth. However, leaf damages are also observed at lower doses when NO_2 is simultaneously present with other air pollutants, in particular SO_2.

NO_2 reacts with water to produce nitric and nitrous acid. The reduction in the sulphur contents of fuels leads to the situation that atmospheric acidity in the industrialised countries is now more and more derived from NO_x rather from SO_2 emissions. Due to the fact that the formation of nitric acid can proceed faster than the formation of sulphuric acid the acidification of the atmosphere and the precipitation through nitric acid is of great importance near emission sources. This has to be considered when discussing the protection of the Maltese limestone heritage. At low light levels NO_2 is further oxidised by O_3 to nitrate (NO_3), which plays a key role in the night-time atmospheric chemistry.

The EU Air Quality Directive (1999/30/EC) for NO_2 gives following thresholds:

- 200 µg/m^3 hourly limit value for human health protection not to be exceeded more than 18 times per year.
- 40 µg/m^3 annual limit value for human health protection.
- 30 µg/m^3 annual limit value for ecosystem protection.

Figure 8 shows the annual averages of NO_2 of the diffusion tube data for the investigation years 2000, 2003 and 2004 for each locality. Figure 9 also shows the annual averages of NO_2 in the form of a bubble chart. The diameter of each bubble is relative to the NO_2 concentration. The bubbles are additionally colour coded in three ranges, smaller than 15 µg/m^3, between 15 µg/m^3 and 30 µg/m^3 and above 30 µg/m^3.

The figures show that localities along main roads are the most affected by NO_2, in particular Floriana, Hamrun and Sliema. The annual averages of Floriana were always above the 40 µg/m^3 annual limit value for human health protection. Regarding individual sites St. Anne Street is by far most severely affected by NO_2 as already discussed in chapter 2.1. with annual averages of 71 µg/m^3 in 2003 and 82 µg/m^3 in 2004. The second highest NO_2 concentration was recorded in both years in Mosta / Constitution Road with 58 µg/m^3 or its continuation the Eucharistic Congress Road with 48 µg/m^3. However, the analysis of the real time measurements made at Floriana station revealed that the 200 µg/m^3 hourly limit value for humans was never exceeded there.

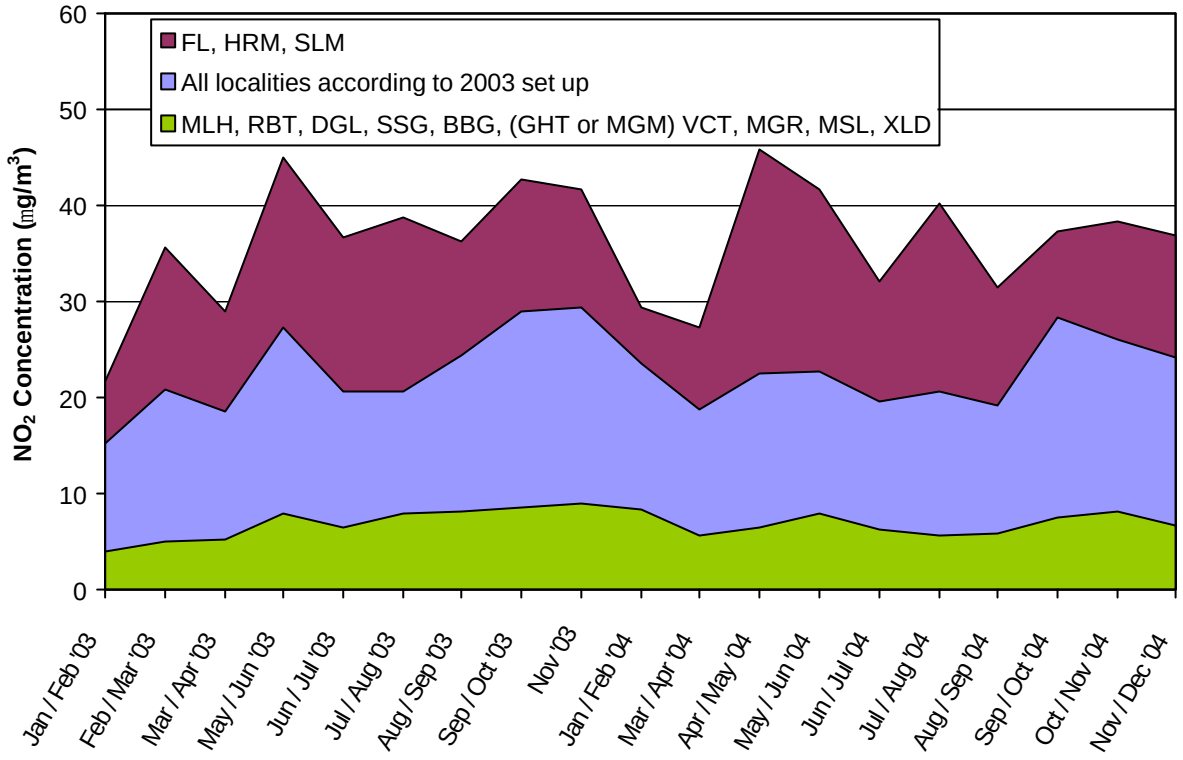


Figure 10:
Temporal development of the averages NO_2 concentration for selected localities and nationwide. For the national averages only those localities, in which measurements were made during the entire time period, were considered.

There was a slight nationwide reduction of 8% from 2003 to 2004. However, Figure 8 shows that in some towns and villages a higher concentration of NO_2 was measured in 2003, others had higher values in 2004. The greatest change was recorded in Floriana, where the NO_2 concentration rose about 6.5 µg/m^3 or about 15% from 2003 to 2004.

It is most likely that the NO_x emissions in Malta are mainly originated from road transport, which obviously are more difficult to pinpoint due to the spatial distribution of the road network itself, but also due to their greater temporal variability. Nevertheless, large-scale combustion facilities such as the power plants but also in industry, also emit significant amounts of NO_x, which is approximately proportional to the energy generated unless countermeasures are taken. Contrary to the efforts to reduce sulphur emissions simply by reducing the sulphur content of the fuel this option is not feasible for NO_x emissions because the nitrogen concentration in the air cannot be reduced.

In Figure 10 the evolution of the averages in selected localities as well as the nationwide average is depicted. As in case of Figure 6 only those towns and villages from which measurements are available over the entire two years period, were considered. The figure does not show a clear seasonal behaviour. The average of the ten selected localities where traffic may be of lesser influence show little seasonal variation. A weak double maximum, around May / June and October / November can be distinguished. Lowest concentrations of NO_2 seem to occur in the beginning of the year. Compared to this, measurements at rural sites on the Northern continent show a distinct winter maximum (due to increased combustion and

lower light levels) and a summer minimum (Warneck, 2000). In Malta, maxima in NO_2 concentrations are more evident when considering the national average or the one for the three most effected localities. In particular the one around May and the one around September / October visible in both years can be explained neither by traffic volume nor electricity generation, and must also be linked to the meteorological situation in spring and autumn.

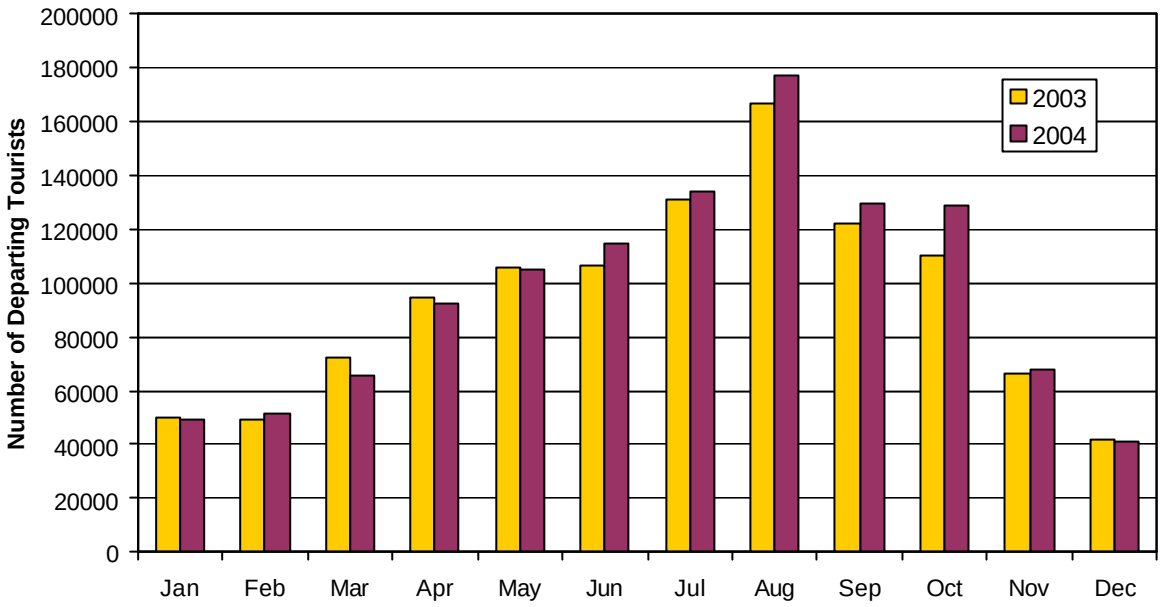


Figure 11:
Total number (air +sea) of tourists departing from Malta (NSO, 2005b).

As already discussed in the previous chapter regarding annual variation of SO_2, there might be several aspects, which may also contribute for the difference in the seasonal behaviour of NO_2 observed in Malta. The seasonal emission pattern, which occurs on the Maltese island, such as transport related to tourism and power generation may be responsible for the fact that NO_2 does not show a minimum in summer as commonly observed on the continent (Figure 7). Figure 11 shows the tourism statistics for 2003 and 2004, while bearing in mind that the entire Maltese population is 400000. As one can see that a peak in the number of tourists is reached in the month of August, during which an equivalent to about 45% of Malta's inhabitants is departing from Malta. However, a detailed impact assessment is needed to quantify the role of tourism on Malta's air pollution situation.

3.3. Benzene

Benzene is a Volatile Organic Compound (VOC), which is present in the urban atmosphere due the incomplete combustion of benzene containing fuel (mainly petrol) or due to evaporation. Cigarette smoke is also a strong source of benzene and therefore of concern indoors. Benzene is carcinogenic and mutagenic and basically any dose, no matter how small, may be considered harmful. The WHO gives, instead of a limit value, a unit risk factor per lifetime of 6×10^{-6} $(\mu g/m^3)^{-1}$, which means that six additional cases of cancer are expected out of a population of one million, when exposed to one $\mu g/m^3$ over its entire lifetime. However,

the EU sets out an annual average target value for benzene of 10 µg/m^3 (or 3 ppbv) to be met by 1st January 2005 and 5 µg/m^3 (or 1.5 ppbv) to be met by 2010.

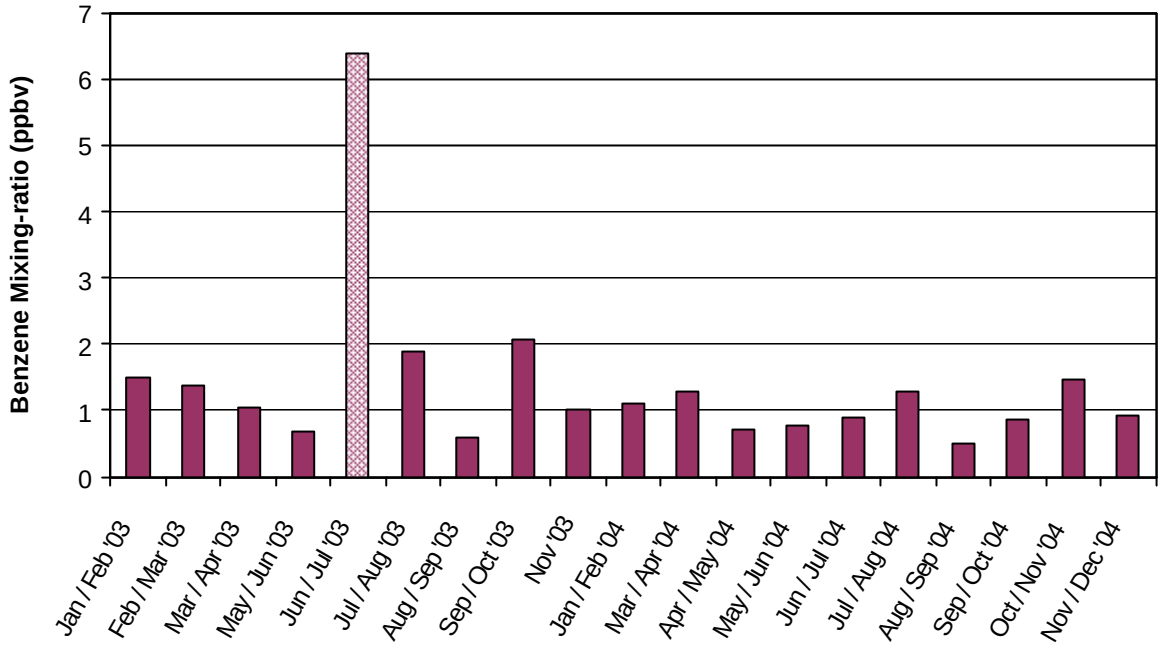


Figure 12:
Histogram of national averages of benzene mixing-ratio measured with the diffusion tube network.

Figure 12 shows the evolution of the benzene mixing-ratio of nationwide averages (all sites) over the entire two year period. As one can see a significant concentration peak took place during the exposure period June / July 2003, which is also visible at almost all individual sites. No explanation can be found apart from an accidental contamination of the samples. This month was therefore not considered in the following analysis.

Figures 13 and 14 show the annual averages of benzene as bar chart and as bubble chart, respectively. The improvement of air quality regarding this specific pollutant since the last SoER is striking. While in 2000 the burden of benzene was alarming in some of the localities many of those came close to the EU 2010 annual limit value of 5 µg/m^3. In 2003 the highest locality average of benzene was measured with 7 µg/m^3 in Fgura, closely followed by Hamrun, Floriana and Birkirkara with 6.7 µg/m^3, 6.5 µg/m^3, and 5.8 µg/m^3, respectively. Particularly high were the benzene levels in Fgura / Hompesch Road (14.7 µg/m^3) and in Floriana / St. Anne Street (12.7 µg/m^3). From 2003 to 2004, a further reduction in the benzene concentration was observed in many towns, in particular those generally most affected by road transport. The biggest decrease happened in Fgura with about 42%. Hamrun is now the locality with the strongest concentration just exceeding the 5 µg/m^3 limit value. However, regarding individual sites the highest value of benzene concentration was recorded in Floriana / St. Anne Street (7 µg/m^3).

Table 4 shows the national averages of benzene mixing-ratio for the three investigation years 2000 (MEPA, 2003), 2003 and 2004. For the computation of the annual average of 2004 only

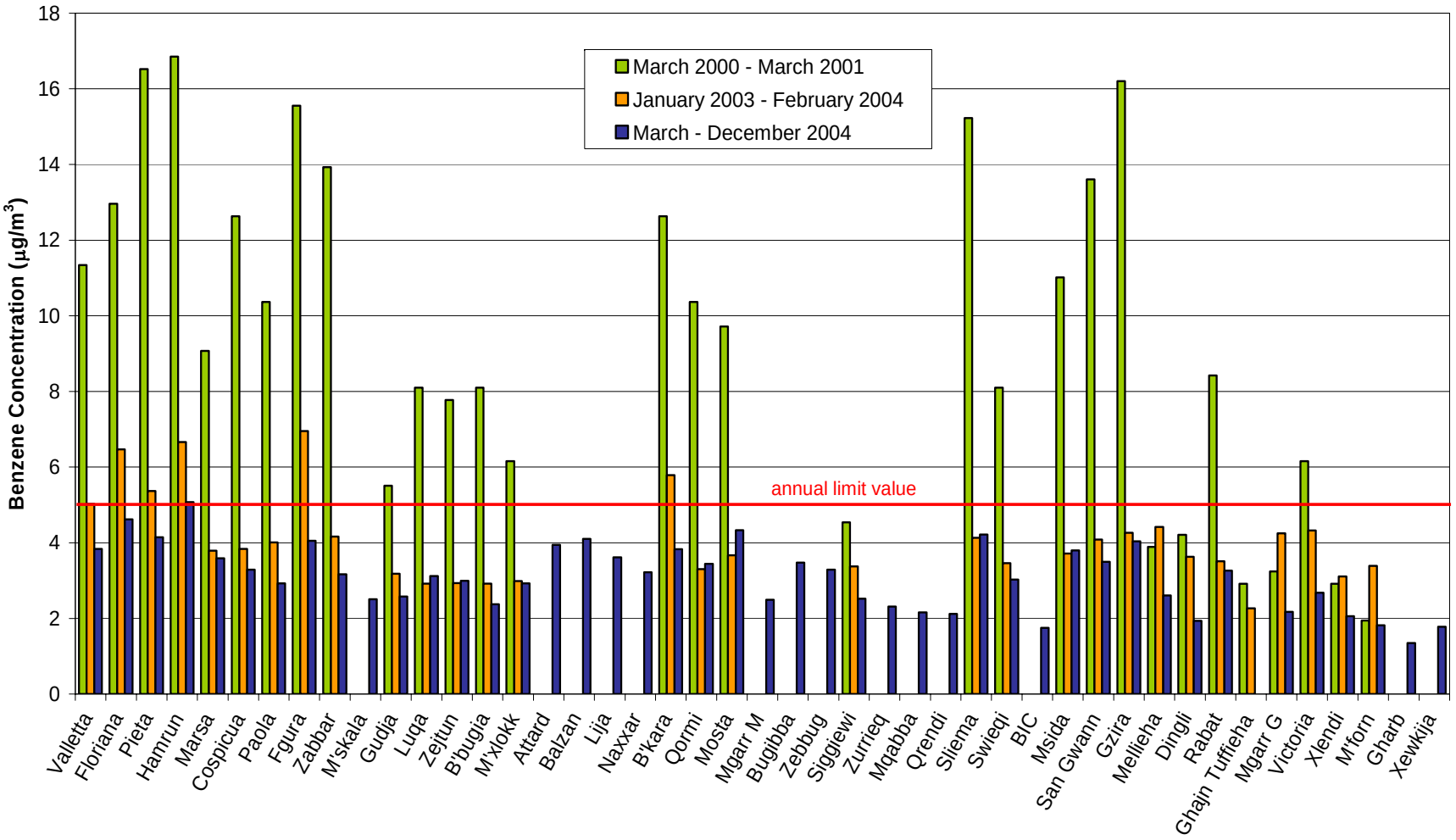
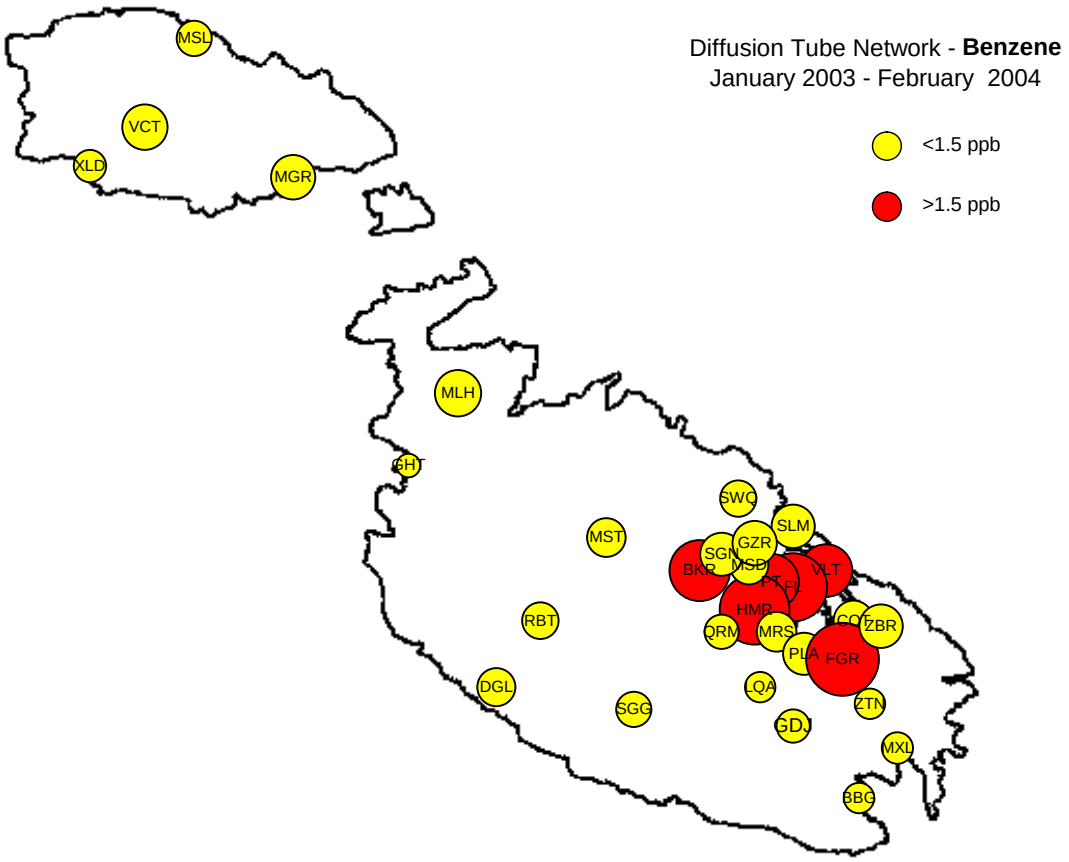


Figure 13:
Annual averages of benzene diffusion tube measurement for the investigation years 2000, 2003 and 2004.



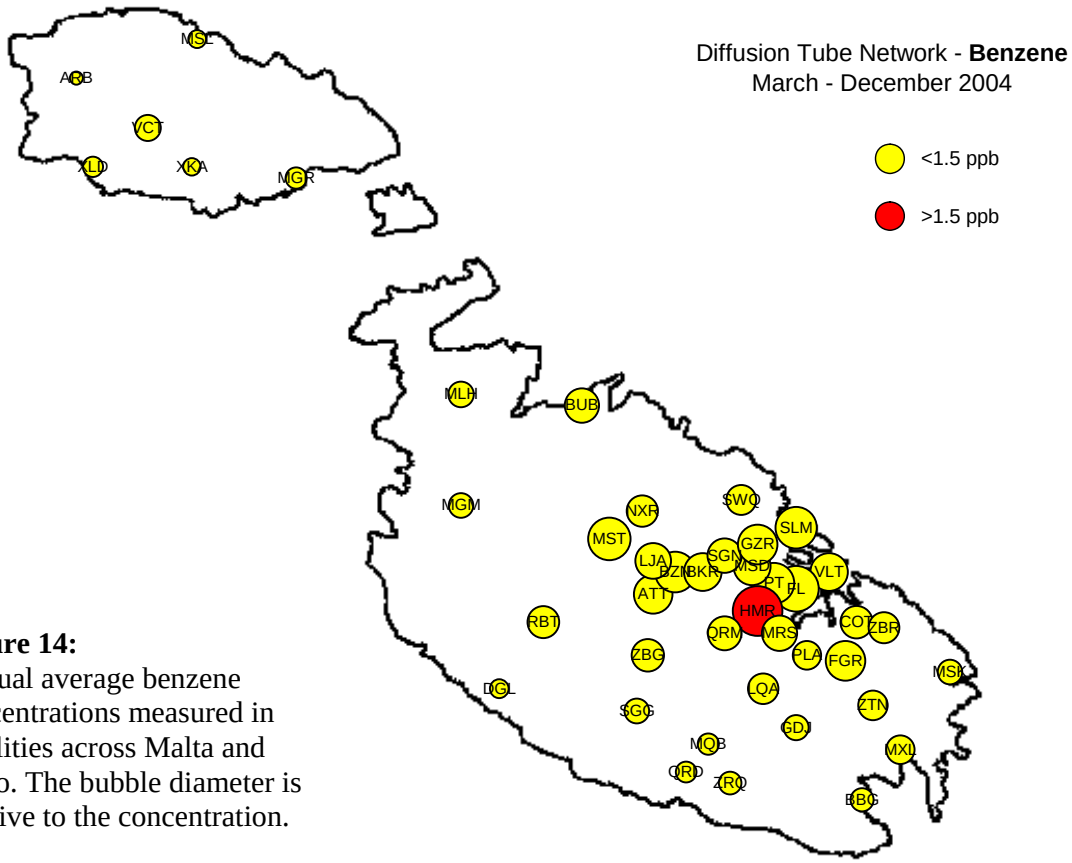


Figure 14:
Annual average benzene concentrations measured in localities across Malta and Gozo. The bubble diameter is relative to the concentration.

those localities, in which measurements were made during the entire time period were considered. The value in brackets in 2003 reflects the average when considering the high values measured in June / July 2003 discussed earlier.

Year	2000	2003	2004
Benzene mix.-ratio	2.83 ppbv	1.29ppbv (1.77 ppbv)	1.0 ppbv

Table 4:
National averages of benzene mixing-ratio measured with the diffusion tube network.

Figure 14 depicts a similar picture regarding spatial distribution as Figure 9 does for NO_2, since within the urban atmosphere both pollutants are mainly derived from vehicle emissions one can expect a more or less apparent correlation between them. Figure 15 shows the correlation of the annual averages of benzene and NO_2 mixing-ratios (each symbol represents one locality) for 2000, 2003 and 2004. The lines represent the linear regression trend line for the given data sets as labelled in the legend. The dashed green line represents the linear regression, when considering the value for Floriana, which lies far off the majority of points. The unbroken line represents the regression line when ignoring this value. For the diffusion tube measurements in 2000 the ratio of benzene to NO_2 was 1 to 5.6 (benzene : NO_2 = 1 : 5.6), which means that one benzene molecule was emitted for every 5.6 NO_2 molecules emitted (or rather formed). This ratio decreased drastically in the years 2003 and 2004 and was 1 to 17.9 (benzene : NO_2 = 1 : 17.9). One should note that the amount of NO_2 found in ambient air depends very much on how much NO is emitted, and how much O_3, hydrocarbons and light is present. This significant improvement regarding the benzene burden

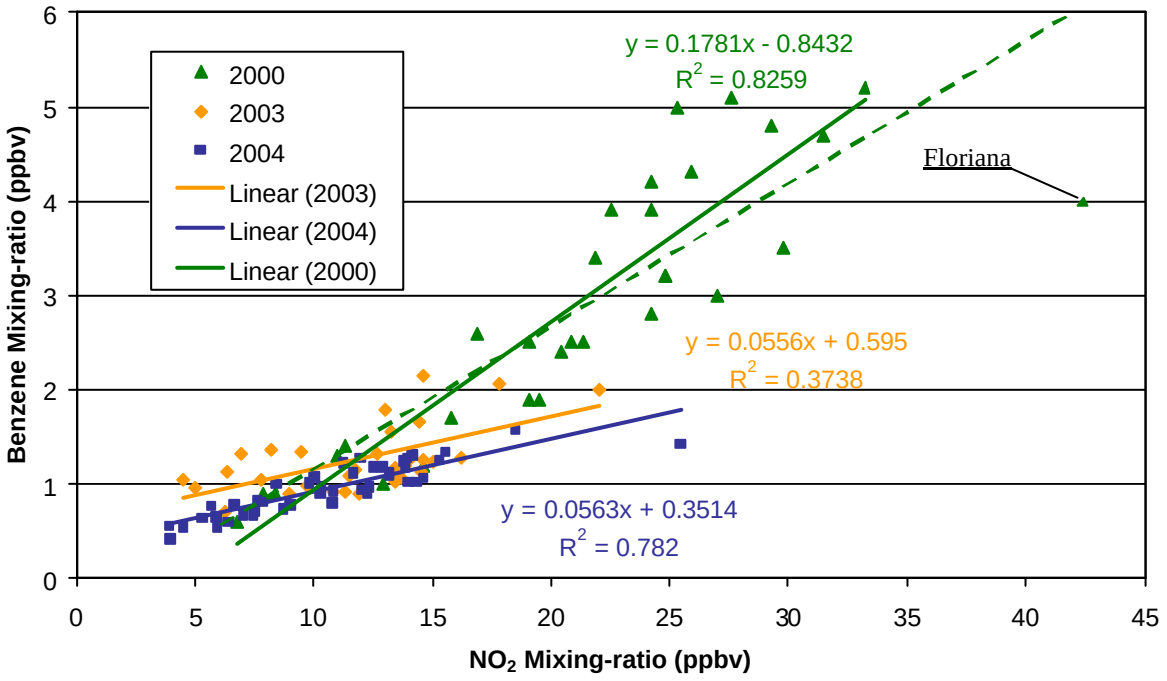


Figure 15:
Correlation of annual benzene and NO_2 mixing-ratios measured in the various localities with the diffusion tube network in the three investigation years (see text for further details).

on the Maltese islands can certainly be attributed to the introduction of lead replacement petrol. Vella et al. (2002) reported very high benzene content between 6% and 8% of leaded petrol used in Malta. According to the NSO leaded petrol was phased out in January 2003 and was replaced by LRP, which now has a benzene content of less than 1% as unleaded petrol.

The introduction of low benzene containing LRP in the beginning of 2003 brought a significant improvement to the air quality regarding benzene. A further reduction of its emission can be best achieved by requiring the installation of a catalyser for newly registered cars compulsory.

3.4. Ozone

O_3 is naturally present in the atmosphere. Approximately 90% of it can be found in the stratosphere, where it filters out the harmful ultra violet radiation from the light we receive from the sun. Some of the stratospheric O_3 is brought down to the ground to level through atmospheric mixing processes and was for long considered the major source of O_3 to be found in the lower troposphere. There are still uncertainties about how much the stratospheric influx contributes to ground level O_3 concentration. In general, *in situ* production of O_3 through photochemical smog reactions involving many other pollutants such as NO_x and hydrocarbons may actually be the main contributor of O_3 found in the troposphere.

Pollutants such as SO_2, NO_x or benzene can be characterised as primary pollutants, which means that their concentrations are expected to be highest next to their source of emission, e.g. such as the stack of a power plant or the exhaust pipe of a car. The situation with O_3 is different. Anthropogenic O_3 is formed as one of several by-products from the photochemical oxidation of hydrocarbons. Key substances, which regulate the amount of O_3 actually present in ambient air are in particular NO and NO_2. Light is also necessary for the formation of O_3 (NO_2 is photo-dissociated to NO and atomic oxygen). High O_3 levels are often found in areas, which favour its accumulation and that of its precursors but also in rural regions, which lie in a certain distance downwind of urban areas. Previous studies have shown that the distance between Malta and Gozo is most of the time not sufficient enough for the photosmog chemistry to compensate for the initial O_3 loss due to high NO levels. In fact, O_3 concentrations measured at Gordan lighthouse are on average lowest, when the wind is blowing from Malta (Nolle, 2001).

O_3 is highly oxidising and respiratory symptoms such as cough, thoracic pain, inflammation of the mucous membranes and therefore increased mucous production, increased risk of infections, alterations of the respiratory tract and a decrease in the forced expiratory volume are observed already in low doses. The effects on health also increase with the time of exposure and with the level of activity during the exposure (such as sports). Unlike SO_2 and NO_2, healthy people are similarly affected as asthmatics or smokers, but great differences are observed from individual to individual.

Long-term effects of low concentrations on flora are in form of impairing the photosynthesis process and resulting therefore in a loss of crops, although there may be no visible injury to the leaves. The short-term exposure to higher levels of O_3 leads to foliar injury evident as flecks on the upper side of the leaves.

The EU Air Quality Directive (2002/3/EC) for O_3 gives the following limit values:

- 120 µg/m^3 8-hourly running average value for human health protection not to be exceeded more than 25 times per year.
- 180 µg/m^3 hourly information threshold for human health protection.
- 240 µg/m^3 hourly alert threshold for human health protection, when exceeded for three consecutive hours.
- AOT40, accumulative dose of hourly averages over the threshold of 40 ppbv, not to exceed 18,000 µg/m^3 hour from May to June for vegetation protection.

Figures 16 and 17 show the annual O_3 concentration measured with the diffusion tube network. For the bubble chart Figure 17 a different colour code was used to emphasise the different chemo-dynamical origin of O_3 compared to other pollutants discussed in the previous chapters. It is difficult to apply the limit values listed above on measurements made with the diffusion network since the tubes were exposed for about a month. However, the figures still give a good overview about the general situation and clearly demonstrate that the O_3 concentrations are lowest in localities, which are most affected by road transport such as Floriana, Hamrun, Fgura or Qormi. Highest values were recorded in villages in the South and the West of Malta and obviously also in Gozo, which lie most far away from the traffic agglomeration. As already shown previously on SO_2 and NO_2, the burden of a specific pollutant in any locality (not just around Malta and Gozo) is determined by a mix of local emissions or *in situ* formation and the importation through transport processes. In case of O_3 the latter is of most significance.

The background measurements of O_3 carried out at Gordan lighthouse / Gozo (Nolle, 2001; Nolle et al. 2002) are the most adequate ones to answer the question of how much O_3 is advected to the Maltese islands. This site is most likely one of the least influenced place by locally emitted air pollution. Since the O_3 concentrations measured in Floriana are one of lowest on the islands, a comparison of both sites should give a very good description of what can be expected in between regarding threshold exceedences.

The number of exceedences of the 120 µg/m^3 human protection threshold at Gordan lighthouse was very high in the previous years with 101 days in 1999, 135 days in 2000, 120 days in 2001 and 107 days in 2002 (Ellul and Nolle, 2003). The 2003 and 2004 data provided to MEPA revealed that this threshold was even exceeded on 133 days in 2003 (from 285 days of measurements available) and on 118 days in 2004 (from 327 days available).

In comparison to the measurements at the lighthouse station the 120 µg/m^3 threshold for O_3 was less often but still exceeded on 45 days (320 day available) at the traffic influenced site in Floriana. Table 5 summarises the exceedences per month at Gordan lighthouse in 2003 and 2004 and at Floriana in 2004 as a percentage of the number of days for which data is available. The table reveals that this threshold was exceeded in 2004 mainly during spring time, but at the background station also during the summer in particular in 2003.

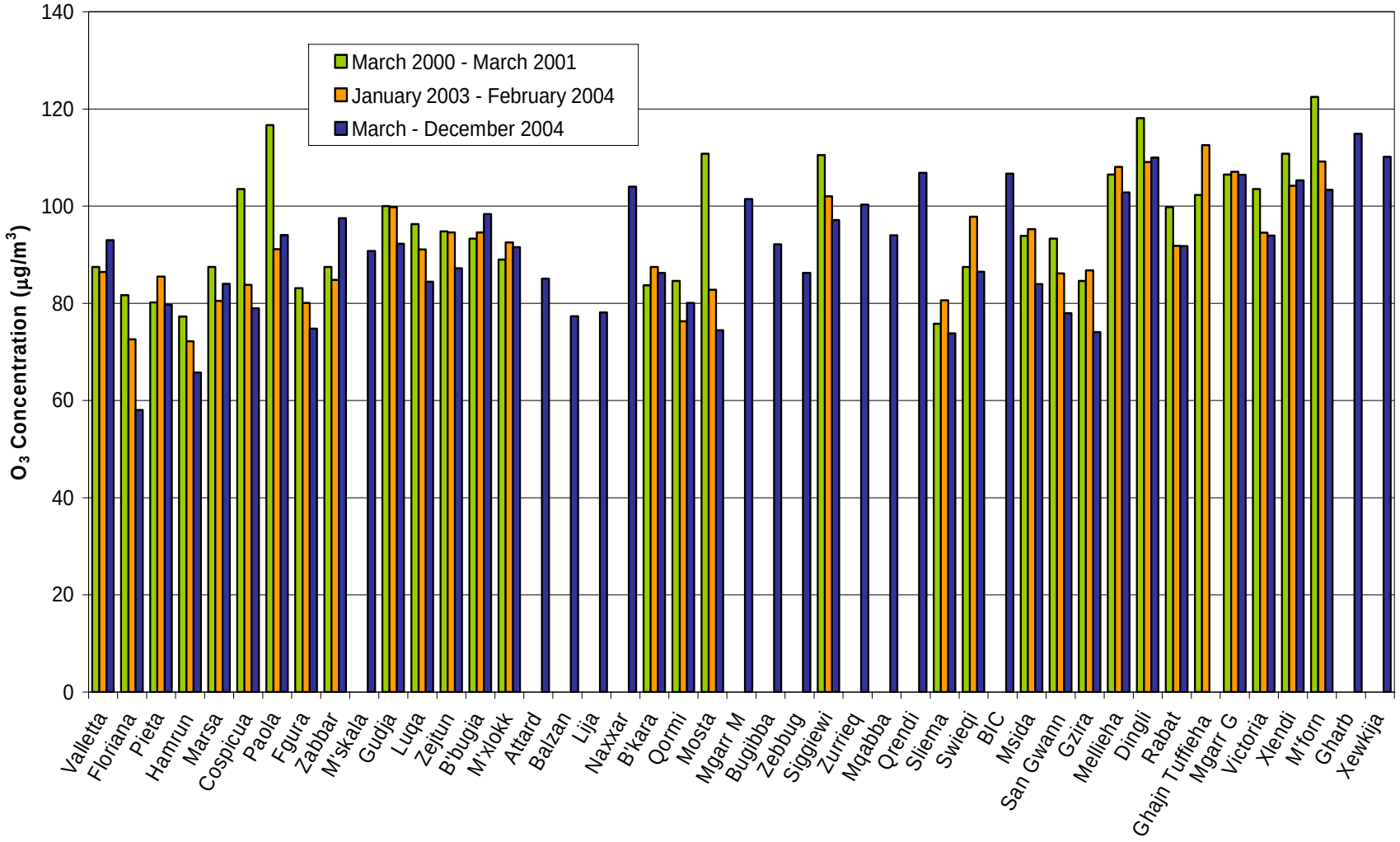
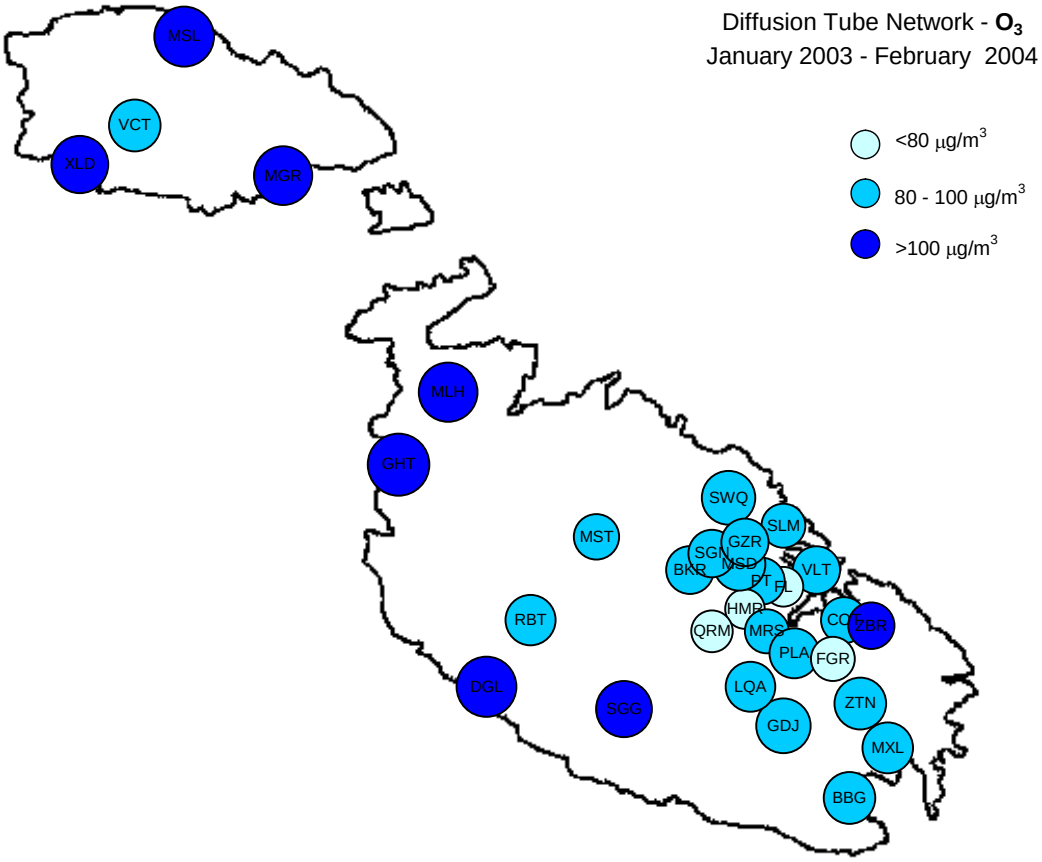


Figure 16:
Annual averages of ozone diffusion tube measurement for the investigation years 2000, 2003 and 2004.



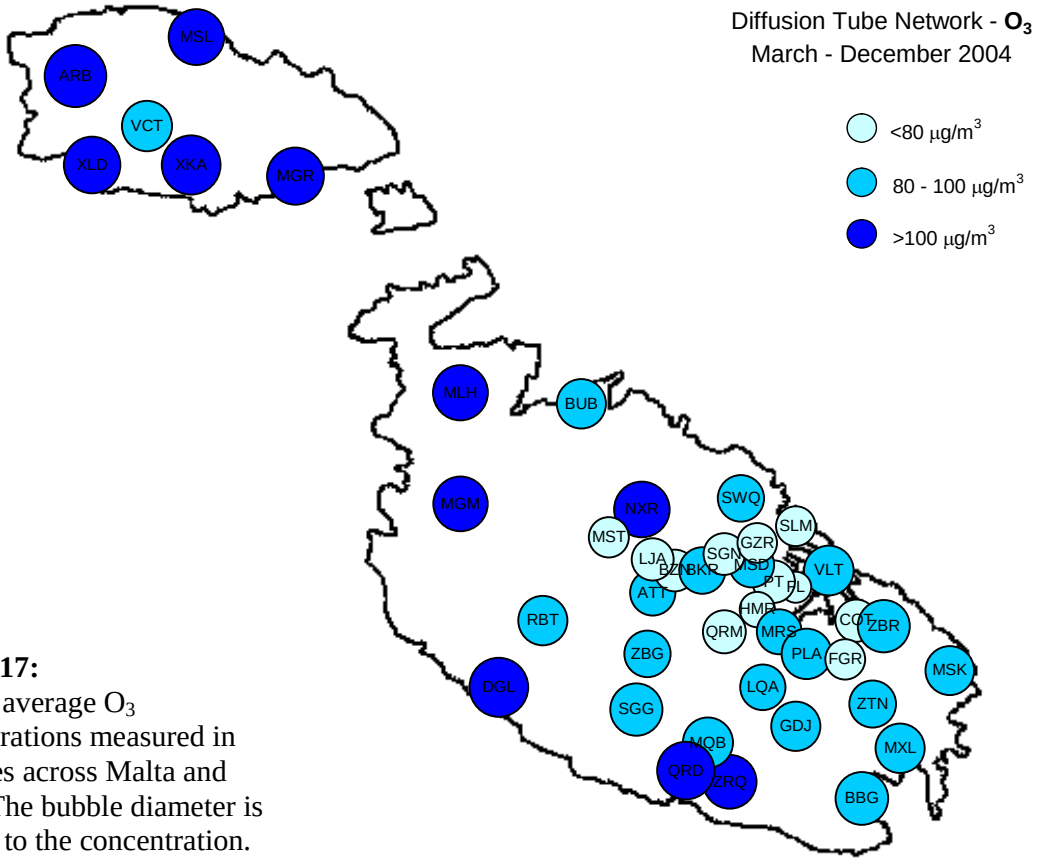


Figure 17:
Annual average O_3 concentrations measured in localities across Malta and Gozo. The bubble diameter is relative to the concentration.

	Lighthouse 2003	Lighthouse 2004	Floriana 2004
Jan	0 (17)	0 (31)	0 (26)
Feb	7.1 (28)	10.3 (29)	21.1 (19)
Mar	72.2 (18)	32.3 (31	56.5 (23)
Apr	77.8 (27)	46.7 (30)	86.7 (30)
May	69.6 (23)	45.3 (31)	3.6 (28)
Jun	69.6 (23)	76.7 (30)	0 (30)
Jul	83.3 (30)	81 (21)	0 (21)
Aug	93 5 (31)	4 (25)	3.4 (29)
Sep	45.8 (24)	40 (30)	0 (27)
Oct	0 (12)	19.3 (31)	0 (26)
Nov	0 (24	0 (7)	0 (30)
Dec	0 (28)	0 (31)	0 (31)
Total in days	**133 days (285)**	**100 days (327)**	**45 days (320)**

Table 5:
Percentage of exceedances per month of the 120 µg/m^3 human protection limit value for O_3 at Gordan lighthouse in 2003 and 2004 and in Floriana in 2004. The number in brackets is the number of days available for each month and year, respectively.

An interesting fact is that compared to the numbers in Table 5 the 180 µg/m^3 public information threshold was hardly exceeded, actually it was never exceeded in Floriana and at the lighthouse the exceedence was only for three days in 2003 and one time in 2004. The exceedences in 2003 are on the 4th August from 17:00 hour to 18:00 hour with 183 µg/m^3, on the 14th to the 15th of August from 21:00 hour to 01:00 hour with a maximum concentration of 195 µg/m^3 and on the 20th of August from 14:00 hour to 15:00 hour in 2003 with 188 µg/m^3. In 2004, this limit value was exceeded on the 10th June from 15:00 hour to 16:00 hour with 185 µg/m^3. Typical photosmog episodes as they are commonly observed on the continents in summer with O_3 levels reaching even the alert threshold for several consecutive days are not observed on Malta so far (Nolle et al., 2002).

The numbers of exceedences discussed above speak for themselves, when keeping in mind that the 120 µg/m^3 threshold should not be exceeded for more than 25 times a year. One can therefore expect that any locality on Malta and Gozo, is strongly affected by O_3.

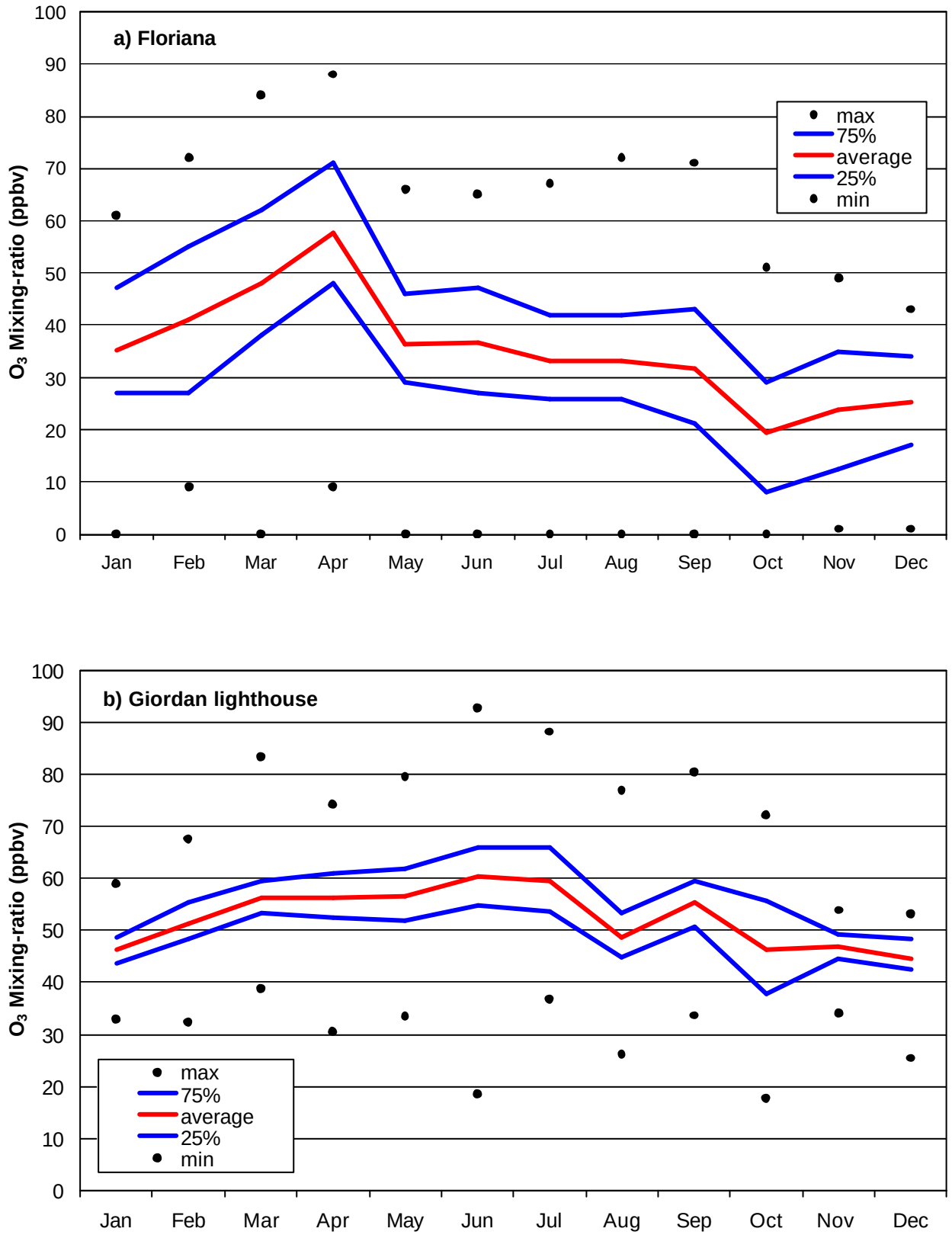


Figure 18:
a) The distribution of hourly averages of O_3 measured at the traffic station in Floriana in 2004.
b) As a), but for the background station at Gordan lighthouse.

Figure 18 shows the distribution of hourly averages of O_3 mixing-ratio measured in Floriana and at Gordan lighthouse. Besides the monthly averages, the 25th and 75th percentiles as well as the minimum and maximum values are depicted. Figure 18a shows minimum concentrations in Floriana can go as low as zero, which happens mostly during rush-hour periods when high amounts of NO are emitted (see also Figure 2), while the background levels at the lighthouse (Figure 18b) remain almost always above 20 ppbv. Maximum values are comparable at both stations. It can also be seen that the O_3 values measured in Floriana spread over a larger range expressed by the distance of the percentiles (blue lines), which is a sign of a greater variation in the concentration O_3. Lesser fluctuations (blue lines are closer to each other) are observed at the lighthouse, which show that the ozone chemistry reached a kind of equilibrium. The monthly averages of O_3 at both sites also clearly differ from each other. The annual behaviour of O_3 at the lighthouse with a spring / summer maximum and a winter minimum is typical for such a background site, although the winter values remain higher compared to other background site in Europe (Warneck, 2000). The discrepancy between the Floriana and the lighthouse O_3 data may be again explained by the combination of meteorology and chemistry. However, more information especially about the prevailing meteorology (wind speed and direction, precipitation) is needed to obtain a plausible conclusion. All locations, but in particular the traffic influenced diffusion tube sites in Figure 10 show one maximum of NO_2 concentration around October, when the O_3 concentration is lowest in Floriana. The meteorological situation during that time of the year with general low wind speeds (Nolle, 2001) and weaker convection may reduce the removal of NO_x and other pollutants, which then destroy the O_3 advected from outside. It was also shown that O_3 levels are on average lowest at Gordan lighthouse, when the wind blows from between east-south-east and south-east, coming from the main island (Nolle, 2001).

The fact that the O_3 levels are highest in the "rural" areas of Malta will certainly affect the agricultural economy in the form of loss of crop yields. The O_3 concentrations found on Malta are normally not high enough to cause visible injury on leaves, but are high enough to impair photosynthesis. A study carried out in Malta on potatoes (Callus, 2000) indicates a loss of crop yield of about 30 % considering an increase from 30 ppbv to 50 ppbv, other stress factors from other pollutants or the lack of water are not considered. The average AOT40 value calculated for the years 1999 to 2002 and applied to Malta's harvest season (April – June), was exceeded by 2.3 times (Ellul and Nolle, 2003).

As already discussed in chapters 3.1. and 3.2. medium and long-range transport influences the air chemistry in the Mediterranean. The lower atmosphere is particularly influenced by emissions from Europe, while the middle troposphere is also influenced by pollution emitted from the American continent (Lelieveld, 2002).

3.5. Suspended Particulate Matter

There is a great diversity of suspended particulate matter (PM) (also called aerosols) in air. Their size ranges from about 0.01 µm (condensation nuclei) to about 100 µm (pollen). Depending on their origin they can have different compositions and different shapes. The two main sources of aerosols are either the dispersal of solid material from the Earth's surface or their formation through chemical reactions and condensation. For Malta important sources of particulates are the sea injecting sea salt into the atmosphere, wind blown dust (locally as well as long-range transported dust in particular from the Sahara), dust directly emitted as through

quarrying or mechanically whirled up dust and tyre and brake abrasion and particulates originated from exhaust emission e.g. of the power plants and traffic.

The effect of aerosols on human health is very much depending on their size, shape and composition. Large dust particles (>10 µm) are filtered by the nasal hairs or get impacted on the walls of the nose, sinuses or throat and do not enter the lower respiratory tract. As the particle size gets smaller, they are more and more easily carried down into the deeper respiratory tract, where they get deposited through impaction. The particle size, which gets most efficiently deposited in that way are the ones of about 2 µm to 3 µm aerodynamic diameter. Particles in the size range between 0.1 µm and 1 µm are too light to become efficiently deposited through impaction, but are too heavy to become deposited through diffusion. Although entering the deeper airways of the lung most of them will be breathed out again unchanged. As the aerosols become even smaller (<0.1 µm), they will be again more efficiently deposited in the alveoli.

There are many ways of measuring PM. However, measurements regarding health aspects are often related to a size range of smaller than 10 µm for the reasons outlined above and is called PM_{10}. The exact definition of PM_{10} is: The mass concentration of particles passing through a size selective inlet that has 50% efficiency at an aerodynamic diameter of 10 µm. However, the actual size distribution and the chemical composition of the PM_{10} measured depend on their origin and are of most importance regarding the effects of PM on health.

Health studies suggest that effects start already at low long-term average concentrations leading to general ill health, decrease in lung function, asthma or even mortality. Obviously, the number of illnesses increases with the concentration of PM and as already stated in the previous chapters the synergic effect of air pollutants as PM are stronger when simultaneously present with other pollutants such as SO_2 and NO_2.

The EU Air Quality Directive (1999/30/EC) gives the following standards:

- 50 µg/m^3 daily limit value for human health protection not to be exceeded more than 35 times per year.
- 40 µg/m^3 annual limit value for human health protection.

The analysis of the three and a half months of PM_{10} measurements carried out in Floriana revealed that the 50 µg/m^3 daily limit value was exceeded in September 2004 on 2 days, in October on 19 days, in November on 8 days and in December on 7 days. This means that the 50 µg/m^3 threshold was exceeded in all on 37 days of 99 days measured (37%), which is eventually also the time of the year with lower ambient dust levels, e.g. due to the possibility of a certain amount of wet deposition. Concentration peaks of up to 300 µg/m^3 were observed and occurred mainly during morning rush-hour periods. The short-term measurements basis for the last SoER (Vella et al., 2002) showed a large temporal and spatial variability in the PM_{10} burden across the Maltese islands.

Figure 2 clearly shows that the PM_{10} measured at the site in Floriana is strongly determined by traffic and concentrations during the rush-hour are about 2.6 times higher than during the minimum at 06:00 hour and still double to what is found during the day. Besides the abrasion of tyres and brakes the secondary formation of particulates may be the determining factor there. These aerosols are likely to be nitric acid and sulphuric acid droplets, ammonium sulphates and ammonium nitrate as well as elemental carbon from diesel vehicles (soot). Ammonia readily reacts with the acids and neutralises them to form ammonium nitrate and

ammonium sulphate particles. The ammonium needed for these reactions is mainly of agricultural and marine origin and has to be advected to this site. However, Camilleri (2004) found relative high levels of ammonia with prevailing west and south-west wind when sampling at a similar site in Msida, which is also strongly influenced by traffic. He also found that about 90 % of the sulphates collected at this site are non-sea-salt sulphates. However, the fraction of non-sea-salt sulphate was also high at the background site on Gozo with about 80 %.

Malta also seems to be strongly influenced by aerosol transported to the islands. An analysis of background measurement of total suspended particulates (not PM_{10}) using a passive sampling method at Gordan lighthouse in comparison with samples taken on Corsica and at Perpignan south-west France revealed several aspects (Loye-Pilot et al., 2004): A much higher amount of total PM is deposited in Gozo, most of which is of marine origin. Also, the non-sea-salt fraction of soluble inorganic elements is also higher at the background site on Gozo compared to the other sites, which might be an indication of a stronger influence of marine traffic rather than continental air masses. Finally, the amount of Sahara dust fallout is also substantial higher on Gozo (about twice as much as on Corsica). The central Mediterranean seems to be stronger effected by Sahara dust than the Western and Eastern Mediterranean basin.

4. Pollutant Standards Index

Many countries around the world introduced a so-called Pollutant Standards Index (PSI) or Air Quality Index. This is done in order to avoid using physical units such as ppbv or µg/m^3, which often appear abstract to the general public. It is also difficult for a non-expert to assess as to whether the values published are being high, tolerable or low; harmful, moderate or harmless, respectively.

For the calculation of the PSI the concentrations of the five classic air pollutants normally monitored, namely SO_2, NO_2, CO, O_3 and PM_{10}, are taken and converted into a dimensionless number. The value 100 is often equalled to the hourly limit value, so e.g. the hourly limit value for SO_2 of 350 µg/m^3 is set to be equal PSI 100. It therefore emphasises the acute effects of short-term exposure to high pollution levels rather than their long-term effects. However, the conversion also does not need to be carried out in a strict linear manner in order to take into account non-linear air pollutants effects on human health. The highest PSI value could then be regularly published even on-line e.g. on MEPA's website. Should one or more pollutant exceed the PSI value of 100 a warning to the public can be issued eventually together with recommendations for sensitive groups within the population like asthmatics. The following Table 6 defines the conversion of trace gas mixing-ratios and PM_{10} concentrations into the PSI and the air quality classification used for this assessment.

Air Quality	Good	Moderate	Unhealthy	Very Unhealthy
PSI	**0-50**	**51-100**	**101-200**	**201-300**
O_3 (ppbv)	55[(1)]	90	180	360
NO_2 (ppbv)	50	100	200	400
SO_2 (ppbv)	30	140	300	600
CO (ppmv)	4.5	9	15	30
PM_{10} (µg/m^3)	50	150	350	420

Table 6:
The conversion of hourly averages of trace gas mixing-ratios and PM concentration into PSI.
(1) The 8 hourly moving average.

Figure 19 shows the frequency distribution of the highest PSI (divided in steps of 10) of all hourly averages measured at Floriana station for the period from mid September until December 2004. Unfortunately, PM_{10} measurements are only available for this period and an evaluation of the entire year 2004 would lead to a distorted result regarding what pollutant generally reaches the highest PSI.

As one can see, the air quality in Floriana is for most of the time (72 %) in the range, which can be considered as good regarding short-term effects on human health. For 25.7 % of the time evaluated the PSI was in the air quality range that can be considered as moderate, while for about 55 hours (2.3 %) the air quality can be classified as unhealthy and susceptible people may experience symptoms. The very unhealthy PSI range above 200 was never reached for the period analysed.

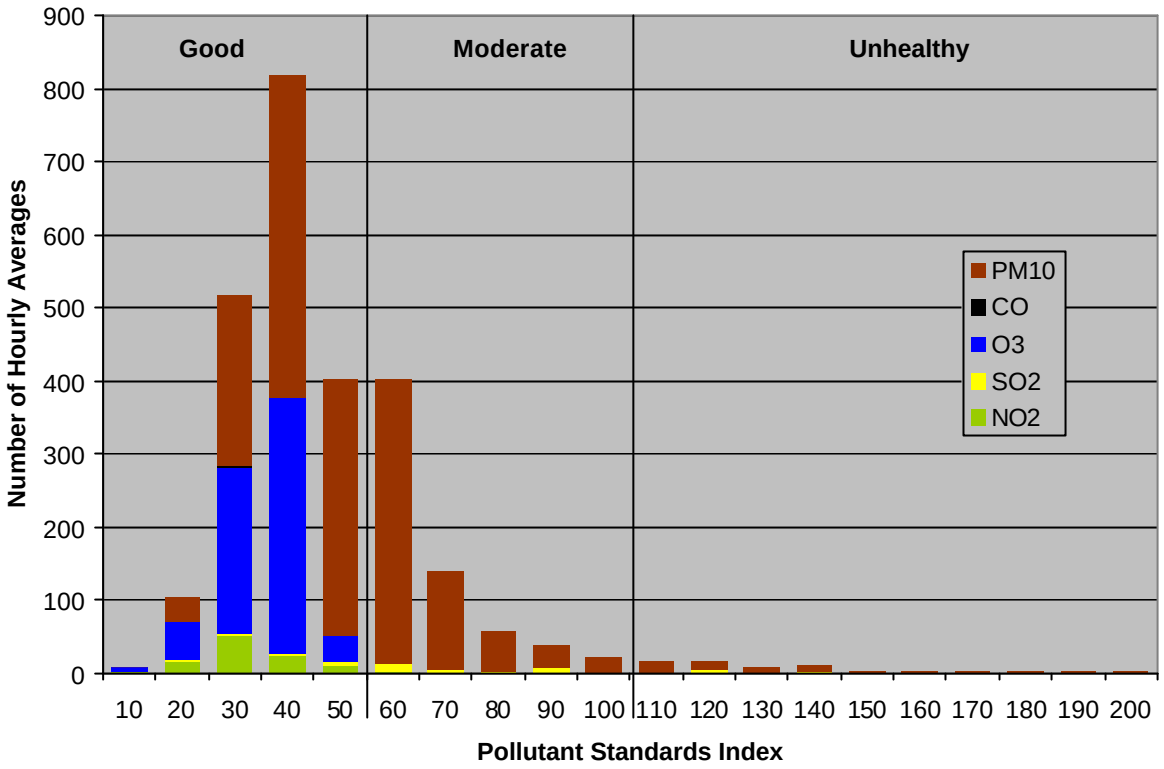


Figure 19:
Frequency distribution of highest PSI (in steps of 10) determined for the measurements at Floriana between mid September and December 2004.

As Figure 19 also shows that the PM_{10} burden at this site is of most concern. PM_{10} is the pollutant, which almost solely reached the "moderate" PSI range from mid September until December 2004. However, it should be remembered that the SO_2 outside the investigated period from September to December 2004 also often exceeded the hourly limit value (see Table 3). In second place the pollutant with the highest PSI is O_3, although it never reached values above 50. As shown in chapter 3.4., one has to consider that O_3 has its annual minimum at this site during that time of the year (see Figures 18). In that regard, a slight shift in the distribution can be expected when analysing future measurements including all seasons, keeping in mind that the PSI emphasises high short-term doses. It must be understood that Figure 19 depicts all hourly averages from mid September until the end of December of 2004. However, it was discussed in the previous chapters that in respect to human health protection, infringements of the hourly limit value of a certain air pollutant should occur for very limited hours per year, only. For example, in case of SO_2 the hourly limit value of 350 µg/m^3 should not be exceed for more than 24 times per year, which is equal to 0.27 % of a year.

One also has to remember that the effects of air pollutants on human health are enhanced when present together at the same time, an aspect which is not considered when calculating and assessing the PSI.

5. Conclusions

Since the last SoER a significant improvement has been observed regarding the SO_2 and the benzene burden on the Maltese islands. These changes can surely be ascribed to the introduction of different (but more expensive) fuels for motor vehicles and for energy generation. However, only a slight nationwide reduction of NO_2 concentrations has been observed and the spatial variability is great. This discrepancy may be related to the overall fuel consumption. In fact the energy demand of the Maltese population is continuously increasing. SO_2 and NO_2 emissions from the power plants could be further reduced by installing flue gas desulphurisation and denitrification facilities. The retrofitting of "low-NO_x" burners, which have a lower peak combustion temperature, would be another alternative to reduce the nitrogen emissions by the power plants.

There are several technical options to reduce NO_x, benzene and PM emissions originated by traffic. The easiest method is to keep the vehicle in good operating conditions. Roadside measurements in other countries showed that about 10 % of the vehicles are responsible for about 50 % of the emissions. Of particular importance is the catalytic converter, which has the purpose to complete the combustion at low temperatures and reduces the emissions of CO, hydrocarbons and NO. Around 75 % of the petrol-engine cars in the UK are equipped with catalytic converters (Colls, 2002). This ratio is certainly much smaller on Malta, but no information about this could be obtained. However, to be fully effective, catalytic converters need to reach an operating temperature of about 300 ºC, which may take a few minutes if not equipped with preheating facilities, a handicap for this technique considering the short distances being usually travelled here. CO and hydrocarbon emissions of diesel engines are generally much lower compared with petrol engines. The main problem of diesel vehicles is their PM and NO emissions. Emissions of particulates can be reduced using filters or traps as well as diesel oxidation catalysts. Such features should be compulsory for newly registered diesel vehicles.

However, the smartest technology will never replace responsible behaviour of every individual. The easiest, fastest and cheapest way to decrease air pollution emissions of any combustion originated pollutants including the formation of ozone is simply by reducing the consumption of fuel for transport and energy generation. Every individual has to be very clear about it in that it is his or her ultimate responsibility to reduce the emissions of air pollution by sensible use of our cars or the need for electricity. Public awareness is most probably the most powerful way to combat air pollution. Incentives such as the additional rebates on the purchase of solar water heaters or electric cars are certainly steps in the right direction to encourage the public to use alternative means for warm water generation and transport. The total fuel consumption can also be reduced by making public transport more attractive or by introducing regulations in the building sector, e.g. the making the insulation of roofs compulsory. Nevertheless, also the energetic promotion of apparent small things such as e.g. the use of energy saving bulbs or car sharing will make a positive impact on the total fuel consumption, when adopted by many people.

There is also enough evidence that the Maltese islands acquire a certain amount of its air pollution burden from outside. In particular the concentration levels of O_3 advected to Malta and Gozo are high in agricultural areas and are of concern from the economical point of view. The combination of transboundary air pollution transport, seasonal pollution sources and the meteorological situation of relative persistent high pressure systems seems to be also the reason for the seasonal anomalies observed for SO_2 and NO_2. However, much more research

is needed to confirm or even to quantify the sources discussed in the various chapters. While the air pollution impact of air traffic on Malta is completely unknown, indicative inventories regarding ship emissions also show that Malta may be strongly affected by this source. Ship emissions may also be responsible for the high amount of non-sea-salt sulphate aerosols found on Malta. It therefore seems to be in Malta's own interest to take initiative to introduce standards for ships, which want to register under the Maltese flag or berth in its harbours, as is done in some other European harbours.

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Appendix

Conversion factors of trace gases from mixing-ratio to concentration:

	1ppbv equals
SO_2	2.66 $\mu g/m^3$
NO_2	1.91 $\mu g/m^3$
O_3	2 $\mu g/m^3$
CO	1.16 $\mu g/m^3$
Benzene	3.24 $\mu g/m^3$

List of the most common abbreviations:

CEN	European Committee for Standardization
CO	Carbon monoxide
DMS	Dimethyl sulphide
EU	European Union
FEV	Forced Expiratory Volume; maximum volume of air that can be exhaled after a full inspiration
H_2S	Hydrogen Sulphide
LRP	Leaded replacement petrol
MEPA	Malta Planning and Environment Authority
$\mu g/m^3$	density
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NSO	National Statistics Office
O_3	Ozone
PM_{10} / $PM_{2.5}$	Particular matter of an aerodynamic diameter equal to 10 µm or 2.5 µm, respectively
ppbv	mixing-ration by volume. For example 50 ppbv of ozone means fifty out of one billion air molecules is an ozone molecule
ppmv	mixing-ration by volume. As ppbv but per one million air molecules.
PSI	Pollutant Standards Index
SO_2	Sulphur dioxide
SoER	State of Environment Report
VOC	Volatile Organic Compound
VRT	Vehicle Roadworthiness Test