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Air Pollution and Health: A Review

Gabriela Camilleri
'Amaryllis' Our Lady of Mount Carmel Street, Munxar, Gozo, Malta, MXR1311, Europe

Abstract: In many countries around the world including in the small Maltese Islands in Europe, air pollution is associated with increased mortality and morbidity rates as reflected by increased hospital admissions and doctor visits not only for respiratory illnesses but also for cardiovascular illnesses. Some studies have found that air pollution is also associated with an increase in respiratory symptoms in lower lung function in children. In the Maltese Islands, air pollution in mostly because of the power stations as well as traffic emissions. During the past decade, the annual mean level of respirable suspended particulates and oxides of nitrogen and ozone have increased substantially. This review will focus on the effects of air pollution on human health with special reference to data obtained locally in the Maltese Islands.

Key words: Particulate matter, sulphur dioxide, nitrogen oxides, benzene, ozone

INTRODUCTION

Air pollution is a major environmental health problem worldwide. The World HealthOrganization considers that air pollution is damaging the resources that are needed for the long-term sustainable development of the planet (Fig. 1). The sources of air pollution fall into three main categories:

- Mobile sources such as combustion-engine vehicles including gasoline-powered cars, diesel-powered vehicles, motorcycles and aircrafts
- Stationary sources which include rural sources such as agricultural production, mining and quarrying; industrial sources such as manufacturing and community sources such as the heating of homes, municipal waste and incinerators
- Indoor sources which include combustion, tobacco smoking and emissions from indoor materials or substances such as volatile organic compounds, asbestos and radon

SPECIFIC AIR POLLUTANTS

Air pollutants are usually classified into suspended particulate matter (dusts, fumes, mists and smokes), gaseous pollutants (gases and vapours) and odours.

Suspended particulate matter: Suspended Particulate Matter (PM) consists of finely divided small particulates with diameters of <10 μm (PM_{10}). Suspended particulate matter comprises a wide variety of substances which include inorganic and organic carbon, acidic or neutral sulphates and nitrates, fine soil dust, residues of lead and other metals, asbestos and other fibres. Small particles efficiently penetrate indoors where levels are typically 70-80% of outdoor levels in the absence of indoor sources. In locations with indoor sources, e.g., cooking or tobacco smoke, indoor levels may be much higher than those outdoors.

The two main sources of particulate matter (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, windblown 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 2-3 μm aerodynamic diameter. Particles in the size range between 0.1 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.

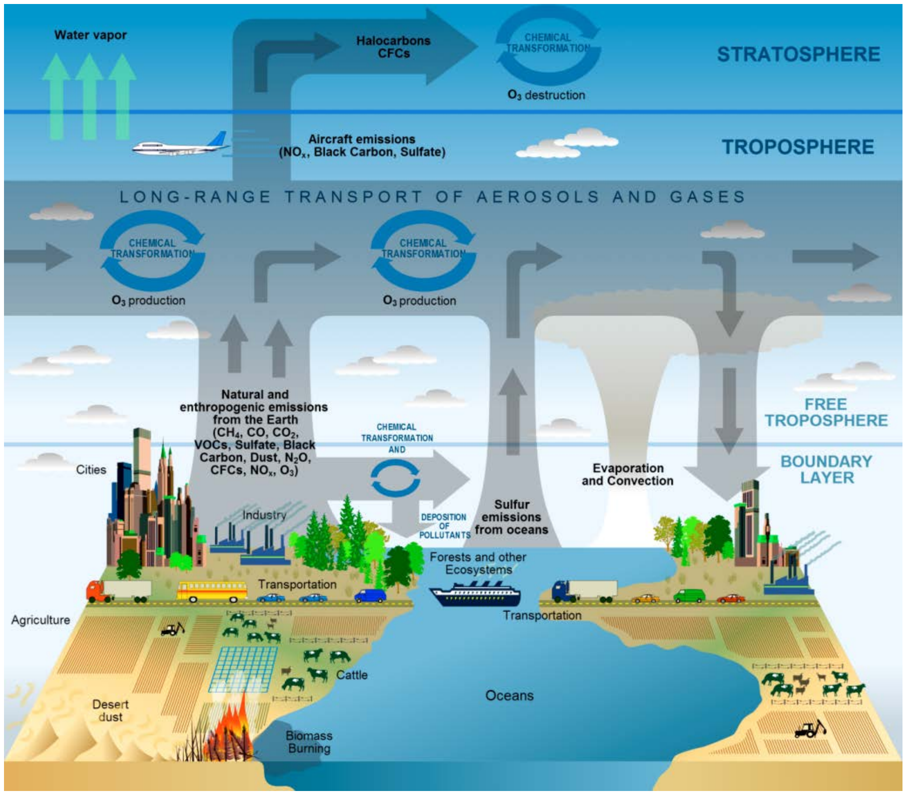

Fig. 1: Scientific modelling: a schematic diagram of chemical and transport processes related to atmospheric composition. Reproduced with permission from http://en.wikipedia.org/wiki/Scientific_modelling

Acid aerosols are a subset of fine particles. Atmospheric oxidation of Sulphur Dioxide (SO_2) may produce sulphuric acid and partially neutralize sulphate salts. The formation of acid aerosols is hastened by humidity and photochemical processes. When individuals with asthma are exposed to acid aerosols, bronchoconstriction is more likely to develop (Folinsbee, 1993; Pierson and Koenig, 1992; Koenig *et al*., 1983).

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 oxidationof Dimethyl Sulphide (DMS) formed as a metabolic product by marine phytoplankton and theoxidation of Hydrogen Sulphide (H_2S) produced by vegetation and from decaying processes insoils by bacteria. These natural sources are believed to contribute to about a quarter of theglobal sulphur content in the air. However, the majority of sulphur emitted into theatmosphere is of anthropogenic origin in form of SO_2 which attributes to about three quarterof the global emissions. 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 sulphuricacid. 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 suchas wheezing, cough and shortness of breath. Long-term exposure to SO_2 may lead tobronchitis.

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 acidaerosols 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.

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 oxidized to NO_2 while NO_2 is subject to continuous photo dissociation 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. The concentration of NO and NO_2 is often mentioned as asum of both being referred to as NOx.

Direct natural sources of NOx are lightning, the oxidation of ammonia (NH_3) and the flux from the stratosphere where nitrous oxide (N_2O) is photo dissociated. However, the majority of NOx 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 oxidized during the combustion process. About 90% of the combustion Nox 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 NOx. New cars need to be equipped with a catalytic converter in order to fulfil the requirements which limits the emissions of CO, NOx VOCs and PM and which came into force on Malta in November 2002. However, only since January 2005, the exhaust emission test is subject tofail a vehicle undergoing the Vehicle Roadworthiness Test (VRT). These measures shouldeither improve or at least stabilize the situation regarding pollution originating from traffic.

While, NO is often considered to be innocuous, it is more and more recognized to be an important agent for cell signaling and therefore cell function in mammals. 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 human health have to be seen in an indirect way. NO_2 seems to promote bacterial infections inthe lung in particular in children. There also seems to be enough evidence that nitratedproteins (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.

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 industrialized countries is now more and more derived from NOx 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.

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 1 $\mu g/m^3$ over its entire lifetime.

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 NOx and hydrocarbons may actually be the main contributor of O_3 found in the troposphere.

Pollutants such as SO_2, NOx 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.

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.

HEALTH EFFECTS OF AIR POLLUTION ON HUMANS

In a recent American Thoracic Society (2000) statement on the adverse health effects of air pollution, the following were considered adverse health effects:

- Any detectable effects on clinical outcomes suchas visits to the emergency department, hospital admissions and mortality
- Symptoms related to air pollution associated with diminished quality of life or with a change in clinical status
- Any permanent loss of lung function
- All reversible loss of lung function in combination with the presence of respiratory symptoms
- Decreased health-related quality of life

Changes in levels of biomarkers and a transient, small loss of lung function that is by itself related to air pollution were not considered to be adverse health effects (ATS, 2000). The evidence for some of the adverse health effects of air pollution is briefly discussed as:

Mortality: Sudden large increases in mortality due to episodes of extreme air pollution have been described in the Meuse Valley in Belgium (Firket, 1936), Pennsylvania, United States (US) and in London, England (Logan, 1953). Studies have shown that mortality is associated with much lower levels of air pollution. In a six-city study in the US, a significantly increased mortality rate ratio of 1.26 was found in the most polluted city as compared with the least polluted city (Dockery *et al*., 1993). The relationship was stronger for fine particles than for other air pollutants. A study that examined mortality in London during the winters of 1958-1972 identified a significant relationship between mortality and levels of particulate matter, SO_2 and black smoke (Schwartz and Marcus, 1990). A multicentre epidemiological study in Europe (St Leger, 1996) was performed to evaluate short-term effects of air pollution on health using time-series analysis. Similar to US studies, an association was found between mortality and daily concentrations of particles, SO_2 and NO_2 with a time lag of 0-5 days.

Associations between air pollution levels and daily mortality counts have been interpreted by some researchers as being due to the effects of air pollutionon frail individuals with severe underlying heart or lung disease the so-called ‘harvesting effect’ (Zeger *et al*., 1999). Some mortality time-series studies, however have found effects across all ages and not just among the very young and the very old. Two cohort studies from the US have suggested that life expectancy may be 2-3 years shorter in communities with high levels of particulate matter than in communities with lowlevels (ATS, 2000).

The time-series studies also seem to indicate that combustion-related fine particles present a greater risk than naturally occurring particles such as dust storms, volcanic emissions and road dust. It has been shown that the level of PM_{10}, O_3 and sulphate particles are independently associated with hospital admissions for asthma (Thurston *et al*., 1991, 1994). The relationship between the PM_{10} level and hospital admissions for all respiratory diagnoses or asthma is a linear one. Studies of visits to emergency departments for respiratory diseases in the US (Samet *et al*., 1981; Schwrtz *et al*., 1994) and Spain (Sunyer *et al*., 1991, 1993) have also demonstrated similar findings. The effects of air pollution on health care utilization may not occur on the same day and can be delayed up to 5 days. A marked reduction in PM_{10} concentration in regions in the US has been associated with a 50% drop in hospital admissions of children for respiratory disease (Pope, 1989, 1991). The estimated decrease was 7.1% in all respiratory admissions with a 10 $\mu g/m^3$ decrease in PM_{10} levels. This observation gives an indication of the public health and economic benefits of reducing particulate air pollution.

Impairment of lung function: Long-term exposure to O_3 has been found to be associated with a lower level of lung function and a fasterrate of decline in lung function (Bates and Sizto, 1987). Furthermore, the combination of O_3 and acid sulphate may be more important than the effects of O_3 alone. In Germany, children aged 9-11 years living in areas with the greatest amount of urban traffic had significantly poorer lung function than those living in areas with less traffic (Wjst *et al*., 1993).

Asthma and allergies: Air pollution is known to be associated with acute asthma exacerbation (Bates and Sizto, 1987; Wjst *et al*., 1993). The relationship is strongest with particles and O_3; the higher the pollution, the higher the number of asthma patients with acute exacerbation. There has been a general increase throughout the industrialized world in the prevalence of asthma and allergies in children. The reason for this increase is not known and there is no clear evidence that air pollution is causally related. However, there are now several experimental studies showing that diesel particles, SO_2 and O_3 can act as an adjuvants which enhance the production of immunoglobulin E antibodies and possibly increase the prevalence of atopic sensitization and asthma (Diaz-Sanchez *et al*., 1999; Riedel *et al*., 1988; Zwick *et al*., 1991).

Cancer: Known or suspected carcinogens such as benzene and other polycyclic aromatic hydrocarbons are detectable in vehicle emissions. Attempts have been made to quantify the cancer risk from vehicle emissions. In Austria, a level of diesel particles of 5-23 $\mu g/m^3$ in the atmosphere has been estimated to yield 1-2.6 additional cases of lung cancer per 100,000 persons per year (Horvath *et al*., 1988). Other studies have shown a significantly increased mortality risk ratio for lung cancer of 1.36 (95% confidence interval, 1.11-1.66) for an increase of approximately 20 $\mu g/m^3$ sulphate particles (Pope, 1989, 1991; Pope *et al*., 1995). It should be pointed out that quantitative assessment of risks from epidemiological data alone is difficult. Even well-performed quantitative risk assessment is based on assumptions. Furthermore, there are multiple confounding factors such as individual susceptibility to exposure and exposure to cigarette smoke. Nevertheless, the fact that these studies have demonstrateda relationship between air pollution levels and cancer mortality provides grounds for concern that air pollution may increase the risks of lung cancer (Chan-Yeung, 2000).

Respiratory symptoms: A greater frequency of wheezing has been observed among children aged 9-11 years living in areas with the highest flow of urban traffic in Munich, Germany (Wjst *et al*., 1993). Another study in Germany has found a significantly higher prevalence of asthma-like symptoms and allergic rhinitis in children aged 12-15 years living near busy roads, especially roads with a high density of trucks (Weiland *et al*., 1994). Studies from the US (Pope and Dockery, 1992; Schwartz *et al*., 1994), Netherlands (Hoek and Brunekreef, 1994, 1993) and Switzerland (Braun-Fahrlander *et al*., 1992) have demonstrated an increase inupper (runny nose, sore throat, head cold and sinusitis) and lower (wheezing, dry cough, phlegm and shortness of breath) respiratory tract symptoms with increased air pollution.

AIR POLLUTION IN THE MALTESE ISLANDS

In the study, diffusion tube measurements from January 2003 till December 2004 were analyzed. The tubes were regularly changed once a month and sent to a lab in the UK for analysis. During this time, the diffusion tube network consisted of 124 locations in 31 towns and villages across Malta and Gozo (Fig. 2 and 3).

Suspended particulate matter: The EU air quality directive gives the following standards:

- The 50 $\mu g/m^3$ daily limit value for human health protection not to be exceeded >35 times per year
- The 40 $\mu g/m^3$ annual limit value for human health protection

The analysis of the PM_{10} measurements carried out in Floriana revealed that the 50 $\mu g/m^3$ daily limit value was exceeded in all on 37 days of 99 days measured (37%). Concentration peaks of up to 300 $\mu g/m^3$ were observed and occurred mainly during morning rush-hour periods.

The PM_{10} measured at the site in Floriana was strongly determined by traffic and concentrations during the rush-hour were about 2.6 times higher than during the minimum at 06:00 h and still double to what was 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 neutralizes 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 adverted to this site. However, Camilleri 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: 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

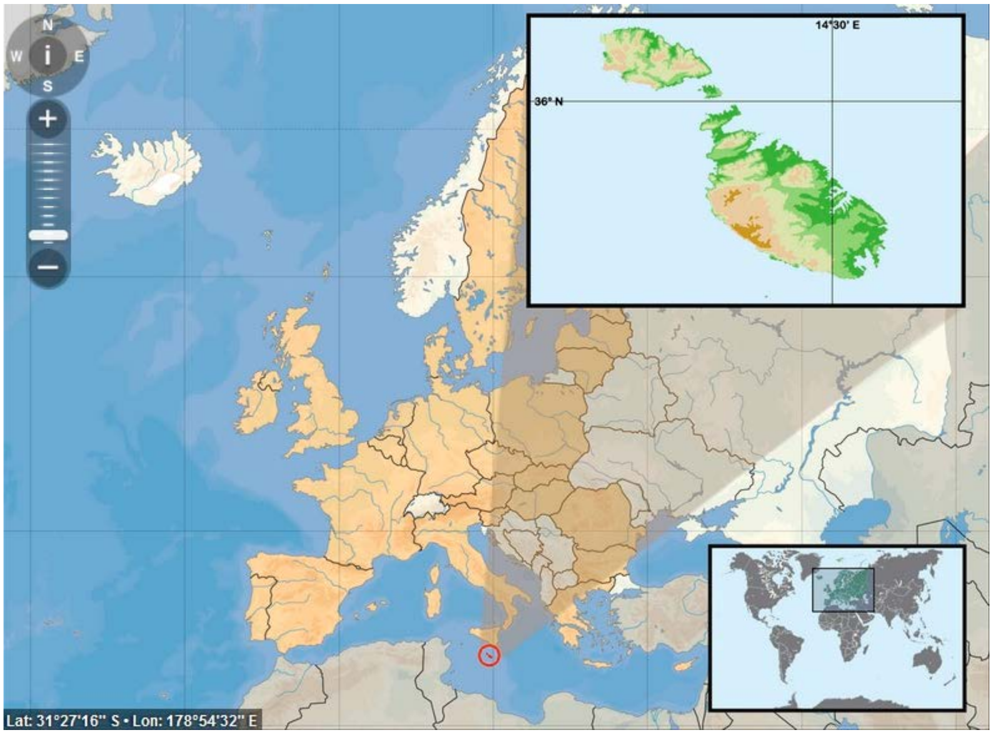

Fig. 2: The position of the Maltese Islands in Europe. Reproduced with permission from http://www.mytripolog.com/2012/07/large-detailed-flag-and-map-of-malta/

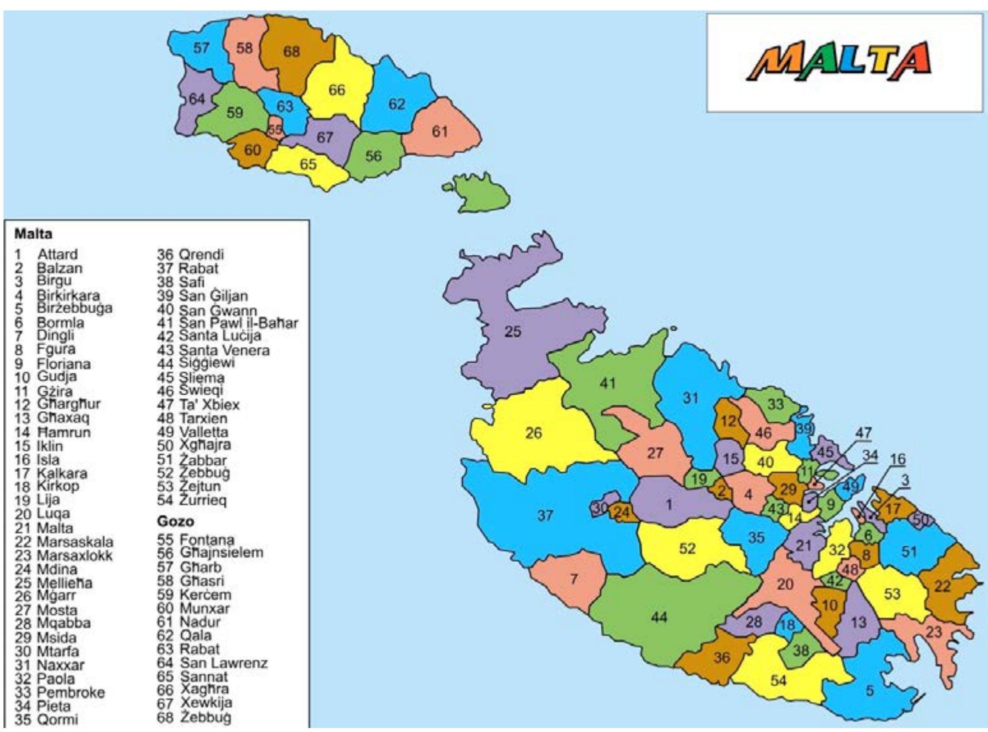

Fig. 3: Map of the Maltese Islands. Reproduced with permission from http://www.mytripolog.com/2012/07/large-detailed-flag-and-map-of-malta/

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.

Sulphur dioxide: The EU air quality directive for SO_2 gives the following thresholds:

- The 350 μg/m^3 hourly limit value for human health protection not to be exceeded >24 times per year
- The 125 μg/m^3 daily limit value for human health protection not to be exceeded >3 times per year
- The 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. These limit values were exceeded 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 h 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.

Local SO_2 sources on the Maltese islands can be specified as the power plants in Delimara as well as the traffic in particular from diesel vehicles. Unleaded petrol and Leaded Replacement Petrol (LRP), the latter introduced in January 2003 are virtually sulphur free. 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.

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 airplanes easily pass over the area of the Maltese islands when landing and taking off. The amount of air traffic is obviously strongly coupled to the tourist season. Jet fuel has a sulphur content of about 0.3% and about 25% of Enemalta's sales comprise that of aviation fuels. Certainly, most of the total fuel an airplane usually carries is used while cruising and emissions are therefore spread along along distance. However, the relative fuel consumption is much higher during takeoff and landing.

SO_2 concentrations published in 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 ineach locality none of them exceeded the annual limit value of 50 μg/m^3 for human protection. However, analysing each site separately, then this value was exceeded in Fgura/Hompesch Road with 61 μg/m^3. This site is also situated in a main road and therefore influenced by boththe 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 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 wasrecorded in Marsa/Spencer Hill with 37 μg/m^3.

Vella also reported an anomaly of a very high SO_2 value in Marsal forn which was in fact above the 50 μg/m^3 limit value. 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.

Another possible source of SO_2 near Marsalforn may be identified as the dumping site a few 10 m 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 SO_2. 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 sewageflows, seem to indicate this probability.

A clear maximum of sulphur dioxide levels was observed on the Maltese islands in summer which is opposite to what is observed even at rural stations on the continents in the Northern hemisphere. 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 marinephytoplankton which may be most productive during the early summer months.

The amount of sulphur emitted by the Power Stations alone may not be responsible for the seasonal variation of SO_2. However, inrecent 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 total energy consumption is steadily increasing and almost doubled since 1990.

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 airplanes and cruise liners.

Nitrogen oxides: The EU air quality directive for NO_2 gives following thresholds:

- The 200 $\mu g/m^3$ hourly limit value for human health protection not to be exceeded >18 times per year
- The 40 $\mu g/m^3$ annual limit value for human health protection
- The 30 $\mu g/m^3$ annual limit value for ecosystem protection

The annual averages of Floriana were always above the 40 $\mu g/m^3$ annual limit value for human health protection. The second highest NO_2 concentration was recorded in both years in Mosta with 58 $\mu g/m^3$. However, the analysis of the real time measurements made at Floriana station revealed that the 200 $\mu g/m^3$ hourly limit value for humans was never exceeded there.

There was a slight nationwide reduction of 8% from 2003 to 2004. It is most likely that the NOx 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 NOx which is approximately proportional to the energy generated unless counter measures 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 NOx emissions because the nitrogen concentration in the air cannot be reduced.

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. In Malta, maxima in NO_2 concentrations are more evident when considering the national average or the one for the three most effected localities.

Benzene: The improvement of air quality regarding this specific pollutant is striking. In 2003, the highest locality average of benzene was measured with 7 $\mu g/m^3$ in Fgura, closely followed by Hamrun, Floriana and Birkirkara. 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 $\mu g/m^3$ limit value.

Vella (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 <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.

Ozone: The EU air quality directive for O_3 gives the following limit values:

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

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.

Typical photosmog episodes as they are commonly observed on the continents insummer with O_3 levels reaching even the alert threshold for several consecutive days are notobserved on Malta so far.

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 impairphotosynthesis. A study carried out in Malta on potatoes indicates a loss of crop yield of about 30% considering an increase from 30-50 ppbv, other stress factors from other pollutants or the lack of water are not considered. The average AOT40 value calculated for the years 1999-2002 and applied to Malta's harvest season (April-June) was exceeded by 2.3 times.

CONCLUSION

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 overallfuel consumption. In fact, the energy demand of the Maltese population is continuously increasing. Currently, in 2015, the Marsa power plant is no longer in use and the Delimara one will be switched to gas-utilizing instead of oil.

There are several technical options to reduce NOx, benzene and PM emissions originated by traffic. The easiest method is to keep the vehicle in good operating conditions. Road side 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. This ratio is certainly much smaller on Malta. However, to be fully effective, catalytic converters need to reach an operating temperature of about 300°C which may take a few minutes if notequipped 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 aswell 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 in dividual. 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 pollutionby 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.

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