SO_2 and NOx emissions from Kuwait power stations in years 2001 and 2004 and evaluation of the impact of these emissions on air quality using Industrial Sources Complex Short Term (ISCST) model

Abstract:

Comprehensive emission inventories for 2001 and 2004 for Kuwait's main power stations located at Al-Doha and Al-Subyia have been prepared. These inventories are inserted, in conjunction with meteorological data, into the Source Complex model for Short Term Dispersion (ISCST4.5) to predict ambient ground level concentrations of sulphur dioxide (SO_2) and nitrogen oxides (NOx) at selected receptors for years 2001 and 2004. The comparison of the results obtained for these two years show the influence of increase in emission rates due to urban and industrial growth. For model validation, computed results are compared with the measured daily average values of SO_2 and NOx collected at a fixed Kuwait Environment Protection Agency air quality monitoring station located at the roof of polyclinic in Rabia. Individual contributions of each power station to the highest predicted values are assessed. The five highest hourly, daily and annual ground level concentration values under prevailing meteorological conditions are compared for 2001 and 2004. It is found that the hourly mean concentrations are strongly influenced by the prevailing meteorological conditions. The effect of meteorological conditions has not been that dominant for the daily and annual mean values and the predicted values for 2004 are higher than 2001, simply corresponding to a high emission rates, especially in summer months. Top fifty daily average values show a slope of 0.806 for 2001 which means that the model predictions are 20% less than the observed levels. However, the predicted slope for 2004 is 0.96 and the model predictions are in very close agreement with the observed data.

Introduction:

The impact of economic and industrial activities on the environment and human health is an ever increasing concern world wide. This is particularly important considering the inevitable rise of the living standards in many parts of the world. There is a very fine line between the meetings of the demands of economic growth and safeguarding the environment. Kuwait is not an exception and following the worldwide trends, its environment requires protection in the face of significant rise in its prosperity.

Sulphur dioxide (SO_2) and nitrogen oxides (NOx) emissions from power stations are major contributors to air pollution in many parts of the world. Sulphur dioxide emission result from the combustion of sulphur containing fossil fuels used in power generation. Kuwait is an arid desert, with a harsh summer that lasts almost half the year. From July to September temperatures rise up to 50ºC in daytime. The climatic conditions combined with rapid urbanization seen in recent years pose a real challenge for air conditioning and refrigeration industries in Kuwait and put a very heavy load on its power generation and distribution infrastructure. It is important to note that per capita energy consumption in Kuwait has increased at an average rate is of 7.7% during the last decade, while in industrial countries this rate is about 2-3% (AL-Temeemi, 1995).

Locally produced heavy fuel oil used in Kuwait for power generation contains about 4% sulphur. Therefore, increased use of heavy fuel oil in Kuwait is a major source of SO_2 emissions. To predict the effect of seemingly ever increasing use of electricity in Kuwait a reliable simulation tool, namely, the Industrial Source Complex Sort Term (ISCST) model (U.S. EPA, 1995), is used in this study. In conjunction with the SO_2 emissions, we have also modeled NOx distribution and compared our results with previously published data of Al-Rashidi et al (2005) which were conducted to investigate the efficiency of existing SO_2 level monitoring stations in the state of Kuwait.

Model Description:

The Industrial Source Complex Short Term (ISCST4.5) model is based on the numerical solution of three dimensional diffusion-convection equation assuming a Gaussian plume mechanism for dispersion. The input required by this model consists of chemical sources in a particular area, their rate of emission, topographical features of the area and meteorological conditions. The dispersion coefficient is derived from the Pasquill-Gaussian and McElroy-Pooler data and the plume rise calculated using the formula of Briggs (Briggs, 1973). For a detailed description of the model, see EPA USA WEB SITE). The model generates dispersion plume characteristics, which in most cases is found to be in close agreement with experimental observations. Two versions of this model are currently available. The first version is the short-term model, which is applicable of predicting the dispersion patterns from a source up to a 25km radius around it. The second is the long-term version, which can be used to cover greater distances over longer time intervals such as a season or a year. Obviously, the accuracy of predictions obtained by this model depends on the degree of the accuracy of the input data, i.e., the emission inventory corresponding to a pollutant source, the meteorological data and the topographical data related to the study area. In the present study we have used the short term version ISCST 4.5 to obtain temporal and spatial ground-level concentrations of SO_2, and NOx as indicators for deterioration in air quality. Most of the previously published studies (e.g. see Al-Sudairawi and Mackay, 1988 and Abdul-Wahab et al. , 1999) have used different versions of the ISCST model. Where appropriate we have compared our results with the data reported in these publications. In particular, we have focused on studies conducted by Rama Krishna et al. (2004) which present assimilative capacity and dispersion of sulphur dioxide and nitrogen oxides from industrial sources in Visakhapatnam bowl area using the ISCST-3 model.

The present simulations are based on three super imposed uniform Cartesian grids with coinciding centers representing the sources (stations) of interest. The grid covers 2400 km^2 plus Rabia area. The sole sources of emissions for sulphur dioxide and nitrogen oxides are assumed the main power stations in Kuwait neglecting a variety of lesser sources.

The first uniform Cartesian grid covers an area of 49km x 49km with grid spacing of 1km consisting of 2500 grid points as receptors. The second and third uniform Cartesian grids each represent 10km x 10km sections with grid spacing of 0.5km and 441 grid points as receptors.

Metrological Data and Description of Power Stations:

The essential input requirements for dispersion modelling are (i) the source information, consisting of stack locations, height, emission rate, inner diameter (at exit point), gas temperature (at exit point) and (ii) the receptor information consisting of location, distance from source and (iii) the meteorological data consisting of wind speed and direction, temperature, inversion layer, mixing height and stability class. Stability class is a category index developed using cloud cover and wind speed which define Pasquill categories (Turner, 1970), which range from 1, referring to extremely unstable to 6 indicating very stable conditions.

In this study, the influence of different pollutants emitted continuously from Doha and Subyia power stations at the neighbouring residential areas has been investigated in great depth (Fig.1). The Doha power generation facilities composed of two thermal power stations, one on the East of 2400MW capacity and had two chimneys each having four stacks. The stack height is 196 m; the exit diameter at 3.5m, exit velocity of the gas is approximately 29.4m/s at 408^oK. The other Power station located at west has 2100 MW capacity had two chimneys consisting of 7 stacks. The stack height is 190 m; the exit diameter at 4.3m, exit velocity of the gas is 29.4m/s at 403^oK. Therefore, in total fifteen stacks are in Doha complex in four chimneys. Subyia power station has same capacity (2400MW) as Doha west and had eight stacks in two chimneys. The stack height is 192 m, the exit diameter at 4.3m, exit velocity of the gas is 28.8m/s at 426^oK.Doha residential area is the closest residential area in the immediate neighbourhood of the Doha complex, at a distance of 6km, while Sulaibikhat residential area is located at 8km in the South-eastern direction of the Doha complex. The Subyia power station is about 25.4 km from Kuwait city in the north-eastern direction. There is a continuous air quality monitoring station in Rabia residential area that is about 16.5km from Doha East and 17.1 km from Doha West and about 39.4 km from Subyia power station.

Emission Inventory:

The emissions from the power stations are mainly due to the types of the fossil fuels burnt that results in the discharge of various pollutants to the atmosphere. Sulphur is prevalent in most types of fossil fuels, which are used for power generation resulting into release of large quantities of sulphur dioxide into the atmosphere. SO_2 and NOx are further oxidized and either deposited through wet or dry process resulting into sulphuric and nitric acids or sulphate and nitrate particulates. All of these substances are harmful to various life forms, particularly humans, and the environment. The major sources of sulphur dioxide emission in Kuwait are the power stations. It is reported that SO_2 emission contributes about 67% of total emission in USA (www.epa.gov) and about 70% in UK (www.enivroment-agency.gov.uk). The power plants are also the major source of the emission of nitrogen oxide (NOx) that contributes almost 22% of total emission in USA and about 25% in UK. Power stations in Kuwait use four different types of fossil fuels all containing varying degree of sulphur. The emissions from the power plants include SO_2 and NOx, which are transformed to Acid Rain or dry deposition and particulate matter in the form of ash. Bouhamra and Abdul-Wahab (1999) reported that traffic in the residential areas of Kuwait is responsible for the emissions of 26% of total NOx of total present in ambient air.

Fuel used in the power stations is provided by Kuwait National Petroleum Company (KNPC) and mainly consists of low sulphur fuel oil, gas oil, crude oil, and heavy oil. The total sulphur contents by weight in these fuels are 0.5, 1, 2.5, and 4%, respectively. However, the Ministry of Electricity and Water (MEW, 2002) most often uses the heavy fuel oil that contains high sulphur contents. Nitrogen oxides, generally represented as NOx, are the generalized category of compounds, composed of Nitrogen and Oxygen in varying concentrations, generally found abundantly in most urban areas worldwide. They are formed because of combustion processes (mainly when fuel burns at a high temperature). These oxides react to produce nitrates and nitric acid that cause smog and acid rain. At high temperatures, oxygen and nitrogen react forming NO and NO_2 and NOx formation increases exponentially as temperature rises. Therefore, the emission rates of SO_2 and NOx were meseared and calculated by Ministry of Electricity and Water (MEW). Al-Rashidi et al., (2005) presented the emission rate of SO_2 as a function of fuel consumption and sulphur content in the fuel.

In order to constitute the SO_2 emissions input into the ISCST model the SO_2 emissions rates are calculated per boiler stack. The total emission rates have been divided by number of stacks to obtain the emission rate per stack (Boiler) for each station. Therefore, the actual emission rate for each stack (source) was multiplied by the emission factor for monthly emission rate variation. The ISCST4.5 model requires meteorological data to be used on an hourly basis format for the entire year.

Metrological Condition of Kuwait:

The State of Kuwait is located in the north-eastern corner of Arabian Peninsula, surrounded by the Kingdom of Saudi Arabia from south and west direction, and the Republic of Iraq from the north and Persian gulf in the east direction. The weather in winter is comfortably cool and during nights sometimes temperature drops to around zero degree. In summer, the mean temperature in July and August ranges from 37°C to 45°C with an average mean daily maximum of nearly 45°C.

Fig.1: Map of Kuwait and location of Doha and Subyia Power stations and Rabia area.

The total area of the State of Kuwait is about 1.8×10^4 km^2. The highest concentration of residential areas is in the eastern coastline of Kuwait Bay occupying only 7% of the total area of the country (Fig. 1). The land surface in Kuwait slopes down gently from west to east. In reality, Kuwait has only two distinct seasons, long summer, lasting almost nine months and short winter about three months duration. Summers are dry and harsh, within a day maximum temperatures reaching of about 50^oC. Summer months are almost intolerable without significant air conditioning, which leads to high rates of power consumption. In summer, winds are considerably turbulent, and are predominantly in north-west direction. This favours effective pollutant dispersion accompanied with a high inversion layer. Winters are mild and damp, with occasional rains, where temperature can fall sometimes to zero degree during nights. Wind conditions in winters are calm, and hence, accompanier with a low inversion layer which gives rise to high pollutant concentration due to low dispersion. There is no observable change in the wind direction, either diurnally or seasonally. As expected the meteorological conditions play a pivotal role in pollutant dispersion affect the ground level concentrations in the residential areas. The meteorological parameters that are expected to affect SO_2 and NOx concentrations are wind speed, wind direction, mixing height, ambient temperature and inversion layer. The mixing height is defined as the height at which vertical mixing takes place (Manju, et al., 2002.).

Wind speed and concentrations of pollutants of a source are inversely related. The perfect dispersion process of pollutants in the atmosphere was possible based on the frequency distribution of wind direction and wind speed (Manju et al., 2002). Therefore, when the wind speed reaches its highest level it helps to reduce the concentration of air pollutants, and thus serves to lower their hazardous effects. On the other hand, slow wind or calm conditions can give rise to build up high concentration in the immediate vicinity of the sources.

Figures (2) and (3) reveal that most of the time, the prevailing wind is from the northwest direction (NW). In 2001 prevailing wind was about 60% from the N-W sector. In 2004 the prevailing winds were about 46% from the N-W sector. Moreover, the frequency distribution of the winds were about 31.1% of wind speed. The recorded values are between 3.3-5.4 m/s for 2001. In 2004 the frequency distribution of the winds were about 60.3% of wind speed recorded to be between 0.5-2.1 m/s. Low to Medium winds blowing from the direction of power stations towards highly populated residential areas can in no doubt increase the possibility of pollution eventually affecting the health of the local population.

Winters in Kuwait are characterized by low temperature; low inversion layers, lesser wind movements, which adversely affect dispersion of pollutants compared to summers, characterized by high temperature, high inversion layers, high wind movements and effective distribution facilitating significant dilution of pollutants.

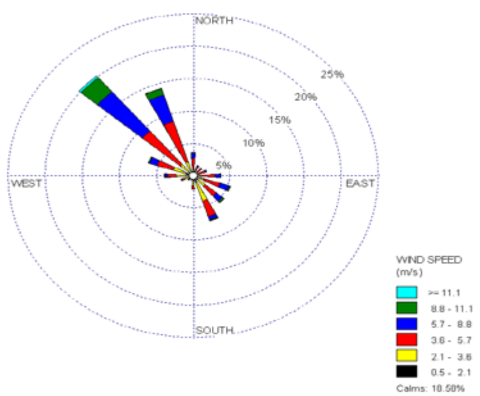

Fig. 2: Wind Rose Plot for Kuwait Airport metrological data for 2001.

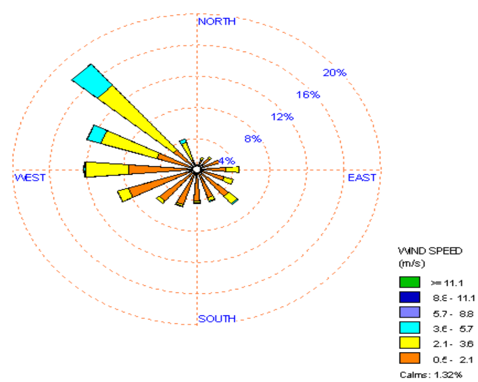

Fig. 3: Wind Rose Plot for Kuwait Airport metrological data for 2004.

Results and Discussion:

To run the model, steady state conditions were assumed with equal amounts of SO_2 and NOx emissions from each stack based on monthly emission inventories. There is no provision for flue gas desulphurization units at Doha Power stations. In addition, the plume depletion, dry or wet was not used. Doha power station stack is considered as a reference for locating the hotspots in regular grid for predicted ground level concentrations.

Comparison of predicted ground level concentrations from both power stations for the year 2001 and 2004 revealed an increase of 18.4% in emission rates and the prevailing meteorological conditions showed a 2% increase in average temperature. In addition, the average wind speed was 3.7m/s for the year 2001 and 4.5 m/s for year 2004, with an increase in average wind speed about 17.8%. These meteorological parameters have adverse effect on ground level concentrations, as they facilitated dispersion and dilution resulting into low values.

Hourly predicted ground level concentrations are strongly influenced by prevalent metrological conditions as they change dilution but it is not possible to counterbalance the effect of high emissions in summer months of year 2004. All the highest predicted values were in the summer period of July to September for both years.

A comparative study for hourly, daily and annual ground level concentrations for 2001 and 2004, have been made. Of the five highest predicted hourly ground level concentrations over the total study area in 2001, the highest hourly predicted ground level concentration of SO_2 is 4421μg/m^3 on the 3rd of August 2001, at 4:00am, at a distance of 1.6km from Doha station and 86° bearing north, the wind speed and temperature corresponding to this maximum were 1.81 m/s and 40^{o}C, respectively. The second high value is 3944 μg/m^3 at a distance of 1.55km from Doha station and 81° bearing north and the third value is 3782 μg/m^3 at a distance of 2km from Doha station and 83° bearing north. The second and third highest values also occur at the day of highest peak at the same hour. However, the next high value is 3729 μg/m^3 on the 6th of August at 2:00am and at a distance of 1.8km from Doha station and 97° bearing north, with wind speed at 2.5 m/s and the temperature at 35^{o}C. This is followed by 3663 μg/m^3 on the 3rd of August at 4:00am, at a distance of 1.55 km from Doha station and 99° bearing north, with wind speed at 1.81m/s and the temperature at 40^{o}C. Comparing meteorological conditions corresponding to these top five values in 2004, it is noticed that the wind speed on the 3rd of August 2004 at 4:00am was 1.68 m/s with temperature at 32^{o}C, similarly on the 6th of August at 2:00am wind speed was 5.14 m/s and with temperature at 32^{o}C. The percentage increase in the wind speed from 2001 to 2004 on the 6th of August was 51.4% while on the 3rd of August a 6.6% reduction in wind speed is recorded. Therefore, these predicted results are in agreement with the theoretically expected trend indicating that high temperature and wind speed significantly facilitate the dispersion of pollutants.

Simulation results for 2004 show that the highest predicted hourly ground level concentration is 3436 $\mu g/m^3$, on the 2^{nd} of August at 12:00pm, 3.5km from Doha station and 174° bearing north, with the wind speed recorded at 4.15 m/s and the temperature at 50^{o}C. This is followed by 3415 $\mu g/m^3$, 3.2km from Doha station and 67° bearing north occurring at the same time as the peak. The third highest value, 3396 $\mu g/m^3$ is at 12:00pm, on the 13^{th} of August, 1.8km from Doha station and 180° bearing north and the wind speed recorded at 4.63 m/s and the temperature at 49^{o}C. The next value is 3302 $\mu g/m^3$ on the 24^{th} of July at 7:00am, 9.5km from Doha station and 115° bearing north with wind speed at 3.1 m/s and the temperature at 45.7^{o}C. The fifth value is 3289 $\mu g/m^3$ on the 11^{th} of August at 12:00pm, 2.8km from Doha station and 180° bearing north with wind speed at 4.15 m/s and the temperature at 47^{o}C.

In comparing the above results with those obtained for 2001 we note that the wind speed on the 2^{nd} of August 2001 at 12:00pm was 2m/s, and the temperature was 44^{o}C. On 12:00pm, on 13^{th} of August 2001, the wind speed was 2.5m/s, and the temperature was 44.2^{o}C, while on 24^{th} of July 2001 at 7:00am, the wind speed was 1.5m/s, and the temperature was 32^{o}C, and on the 11^{th} of August 2001, at 12:00pm, the wind speed was 2.5m/s, and the temperature was 47^{o}C. Therefore, the percentage increase in the wind speed from 2001 to 2004 on 2^{nd} August was 52%, on 13^{th} August was 46%, on 24^{th} July was 52%, and that on 11^{th} August was 40%. This corresponds to a related decrease in the highest predicted ground level concentrations, from 4421 $\mu g/m^3$ to 3436 $\mu g/m^3$ (22%, which is almost equal to the increase in the wind speed of 17.8%).

As shown in the hourly results the distances of the highest predicted concentration values for 2004 is further away from the reference power station than 2001. This is because of the metrological condition such as wind speed and temperature which in 2004 were higher than 2001. Again these results provide numerical confirmation for the correspondence between the pollutants concentration peaks and meteorological conditions.

In contrast to the hourly data the daily and annually average concentrations predicted for the ground level are strongly dependant on emission rates and the influences of metrological parameters is dampened. This is due to averaging of the hourly data. The predicted daily concentrations of SO_2 at the ground level over the total study area in 2001, the highest recorded concentration is 931μg/m^3 on the 9th of July 2001. The highest daily concentration recorded for 2004 is 1224 μg/m^3 on the 26th of June. This corresponds to an increase of 23.9%. The second highest value for 2001 is 893μg/m^3 on the 12th of August and 1054 μg/m^3 on the 18th of July for 2004 (15.3% increase). The third highest value for 2001 is 893μg/m^3 on the 2nd of September and for 2004 is 1052 μg/m^3 on the 27th June (15.11% increase). These values are followed by 870μg/m^3 on the 16th of July for 2001 and 1045 μg/m^3 on the 24th of June for 2004 (16.75% increase). Finally the fifth highest value for 2001 is 851μg/m^3 on the 23rd of May and is 1025 μg/m^3 on the 8th of September for 2004 (17% increase). The location of the top five daily predicted values for 2001 is 1.4km from Doha power station 157° bearing north and for year 2004 is again 1.4km from Doha station and 157° bearing north except the second highest value which is 1.65km from Doha station 127° bearing north. The increase in the ground level SO_2 concentration for year 2004 as compared to year 2001 confirms similar increase in emission rates for the these two years which is about 18%.

A similar analysis of the five highest predicted annual ground level concentrations of SO_2, shows an average ground level concentrations increase of 17.6% between 2001 and 2004 which corresponds to an average 18.4% increase in emission rate between these two years. This increase is due to exactly 18.4% increase in demand for electric As mentioned earlier in the calculation of daily and annual concentration levels the meteorological conditions are averaged resulting in the strong dependency of the results on emission rates.

A similar analysis has been made using the predicted values of nitrogen dioxide (NOx). In the hourly predicted concentrations, the five highest predicted concentrations in 2001, are 421μg/m^3, on the 3rd of August 2001 at 4:00am, at 1.6km distance from Doha station and 86° bearing north, the wind speed and temperature corresponding to this maximum were 1.81 m/s and 40^{o}C, respectively. The second high value is 374μg/m^3, at 1.5km distance from Doha station and 81° bearing north, the third value is 368μg/m^3, at 2km distance from Doha station and 83° bearing north, the forth value is 342μg/m^3, at 2.6km distance from Doha station and 88° bearing north and the fifth value was

341μg/m^3, at 2km distance from Doha station and 97° bearing north. All these maximum predicted values also occur at the day of highest peak at the same hour but at different locations. Comparing meteorological conditions corresponding to these top five values in 2004, it is noticed that the wind speed on the 3rd of August 2004 at 4:00am was 1.68 m/s with temperature at 32.5^{o}C. The percentage decrease in the wind speed from 2001 to 2004 on the 3rd of August was 7.2% and in temperature 18.75%. It is clear from the above results there was no big difference in the wind speed between 2001 and 2004, so that the emission rate will take the major effect.

The predicted results of NOx for 2004 show that the highest predicted hourly ground level concentration is 395μg/m^3, at 10.4km distance from Doha power station and 67° bearing north and the second value is 390μg/m^3, at 12.6km distance from Doha power station and 66° bearing north. The first and second highest values occur on the 18th of July at 5:00am with wind speed 1.68m/s and temperature 35^{o}C. In addition, the third high value is 389μg/m^3, at 14.6km distance from Doha power station and 86° bearing north, the fourth high value is 388μg/m^3, at 13.6km distance from Doha power station and 85° bearing north and the fifth value is 384μg/m^3, at 15.6km distance from Doha power station and 94° bearing north. All these three values were occurred on the 18th of July at 6:00am, with wind speed 1.8m/s and temperature 34^{o}C. However, the comparing meteorological conditions corresponding to these top five values in 2001, it is noticed that the wind speed on the 18th of July 2001 at 5:00am and 6:00am was 1.21 m/s with temperature at 34^{o}C. The percentage increase in the wind speed from 2001 to 2004 on the 18th of July at 5:00am was 28% and 2.8% in temperatures and at 6:00am was 32.8% with no change in temperatures. Therefore, these predicted results are in agreement with the theoretically expected trend indicating that high wind speed and temperature significantly facilitate the dispersion of pollutants.

As we see from the above results for the highest five values, there was no big change in the metrological conditions between both years 2001 and 2004. The emission rate will take the major effect in this case so that the predicted ground level concentrations for year 2004 were grater than year 2001 except the first value, which is almost, equals.

In the case of daily and annual ground level concentrations of NOx the predicted values are strongly dependant on the emission rates and the influences of metrological parameters is dampened. This is due to averaging of the hourly data. The first highest daily predicted concentration of NOx that cover the total study area is 79μg/m^3 on the 9th of July for year 2001 and 109 μg/m^3 on the 26th of June for 2004. This corresponds to an increase of 27.5%. The second highest value for 2001 is 78μg/m^3 on the 3rd of July in year 2001 and 100μg/m^3 on the 18th of September for 2004 (22% increase). The third highest value for 2001 is 75μg/m^3 on the 21st of August and for 2004 is 99 μg/m^3 on the 15th of July (24.3% increase). The forth value is 74μg/m^3 on the 9th of July in year 2001 and for year 2004 is 99μg/m^3 on the 22nd of August (25.25% increase). Finally, the fifth maximum value for year 2001 is 74μg/m^3 on the 9th of July and is 97μg/m^3 on the 3rd of September 2004 (23.7% increase). The location of the top first and third values daily predicted values of 2001 was at 1.3km distance from Doha power station and 157° bearing north and for second, forth and fifth were at 0.5km distance from Doha power station and 59° bearing north. For year 2004 the predicted first, second and fifth values were at 1.4km from Doha station and 157° bearing north except the third value which at 1.7km distance from Doha station and 122° bearing north and the forth value was at 1.25km distance from Doha power station and 179° bearing north. The increase in the daily ground level NOx concentration for year 2004 as compared to year 2001 confirms almost similar increase in emission rates for the these two years which is about 22.9%.

A similar analysis of the five highest predicted annual ground level concentrations of NOx, shows an average ground level concentrations increase of 17.4% between 2001 and 2004 which corresponds to an average 22.98% increase in emission rate between these two years. This increasing is related to the increasing in the demand of electricity and water desalination. However, in the calculation of daily and annual concentration levels the meteorological conditions are averaged resulting in the strong dependency of the results on emission rates.

The air quality monitoring station located on the top of the polyclinic in Rabia provides observed data to study the impacts of ground level concentrations of pollutants.

This data is also used to evaluate the predicted concentration values obtained from the mathematical model in order to validated. In some cases model parameters, such as the dispersion coefficients, can be adjusted within theoretically acceptable range to calibrate the model.

Figures (4) and (5) provide comparison of model prediction and observed data.

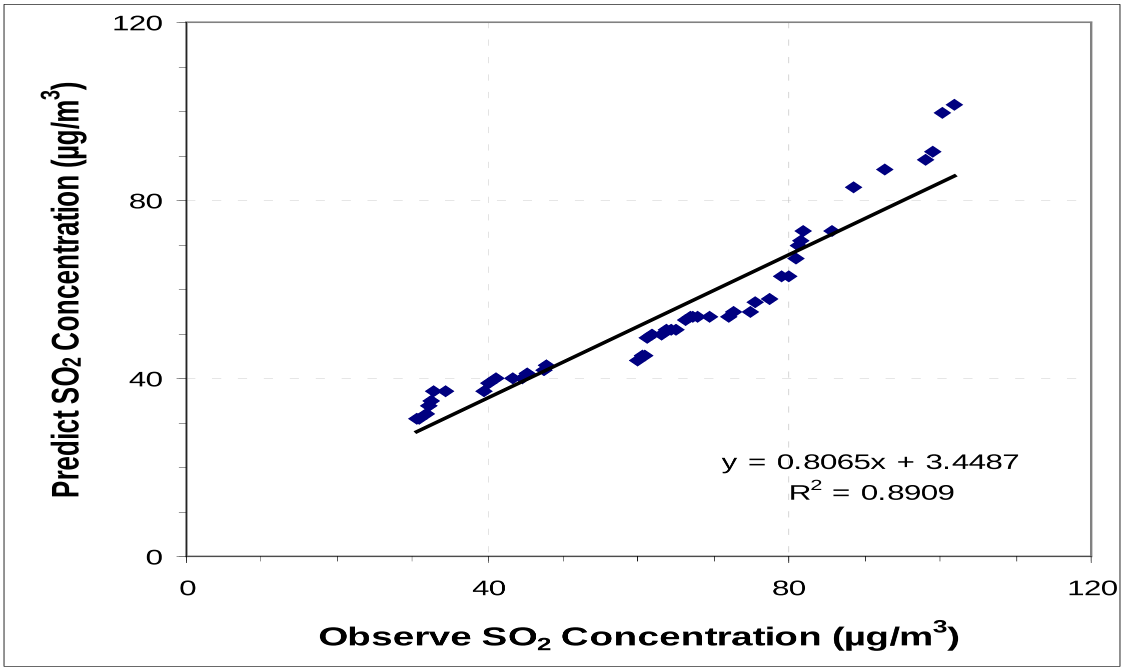

Fig.4: The Highest fifty Values of the Predicted Daily Concentration of SO_2 (µg/m^3) V.S. The Highest fifty Values of the Observed Daily Concentration of SO_2 (µg/m^3) in year 2001 at Rabia

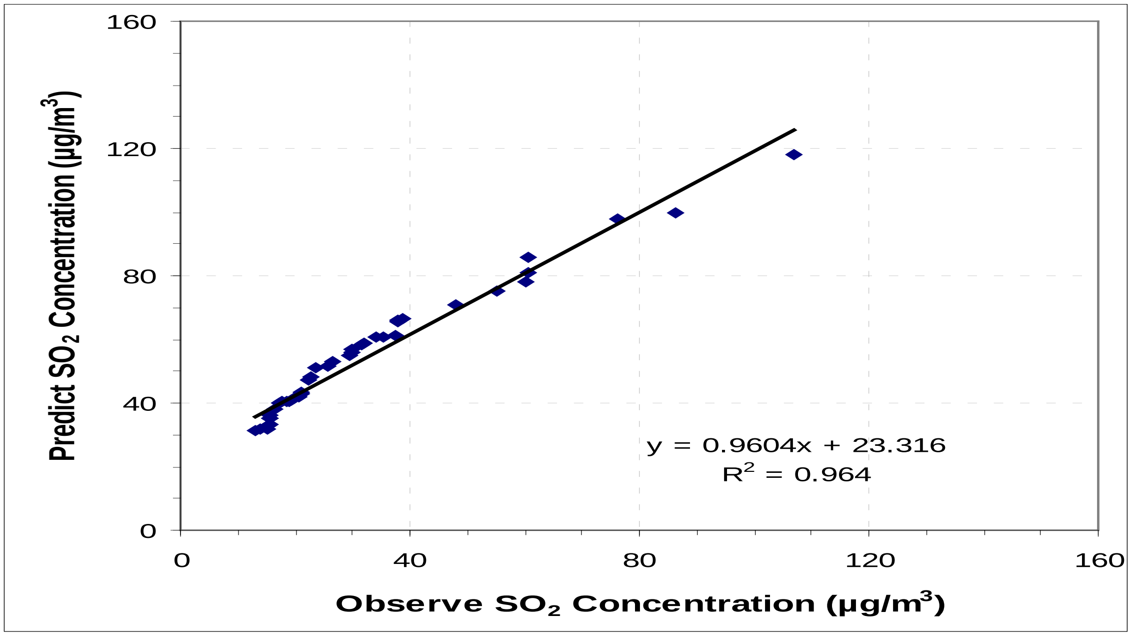

Fig.5: The Highest fifty Values of the Predicted Daily Concentration of SO_2 ($\mu g/m^3$) V.S. The Highest fifty Values of the Observed Daily Concentration of SO_2 ($\mu g/m^3$) in year 2004 at Rabia

For evaluation of the performance of model, the predicted values of the model were compared with the actual real time measured values. In this study, the actual real time measured values have been obtained for sulphur dioxide, from the monitoring station located above the polyclinic in Rabia area. Figures (4) and (5) show that the slope of the daily predicted ground level concentration of SO_2 against the observed values equal to the 0.806 for 2001 and 0.96 for 2004. The lower value of slope in 2001 was mainly due to other sources, cargo depot and auction market that are located in the northwest of the monitoring station with distance of 1.5km, contributing into concentrations built up. In 2004, the cargo depot was moved to a faraway location, with another additional source of SO_2 being close down of an auction market of vehicles. It should be noted that the results presented in this study do not take into account the SO_2 background concentration and the validity of the model is quite appropriate.

Conclusions:

The harsh weather conditions in Kuwait results in temperatures approaching mid $50\,^{0}$C in summer. To counteract the difficult living conditions resulting from this very high power consumption are normal during these months in Kuwait. This in turn gives rise to high air pollutants emissions from power stations. However, these months are characterized by high winds causing severe dust storms that disperse the high pollutant emissions. These two contradictory factors result in a complex pattern of high ground level concentration of pollutants dominated by meteorological conditions. Computer modelling can hence be used as a convenient method for the prediction of the effects of using various types of fuel under various meteorological conditions to minimize the impact of high gaseous pollutants emissions. In the present work a comprehensive modelling of ground level concentrations of sulphur and nitrogen oxides at various residential areas of Kuwait has been carried out. Detailed numerical data obtained by this modelling has been used to study the effects of meteorological conditions and types fuel used for power generation during the for 2001 and 2004. This shows that hourly predicted ground level concentrations are strongly influenced by prevalent metrological conditions suppressing the effect of the high emissions in 2004. On the other hand daily and annually average predicted ground level concentrations are strongly dependant on emissions rate and the influences of metrological parameter is reduced As the natural conditions during these two years were markedly different the analysis presented here provides a general picture of the impact of power generation on the air pollution in the residential areas of Kuwait.

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