Assessment of Ambient Air Quality in Al Jahra Governorate, for 2008

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***Abstract*—**Air pollution is considered to be the one of the most vital problem to all kinds of life. Air pollutants have no borders and can severely influence life on the planet earth. This work analyzes the air pollution yearlong hourly mean continuous data from one of the monitoring station located at the top of polyclinic in Al-Jahra city in the State of Kuwait. The measurements cover major pollutants such as carbon monoxide, methane, particulate matters (PM10) and nitrogen dioxide (NO_2). Furthermore the study also includes meteorological parameters, solar intensity, temperature, and wind speed and wind direction. The seasonal variation for the year of 2008 is investigated (winter, spring, summer and autumn) for these pollutants. The study show daily averages and hourly maximum concentrations for each season of year 2008. The impacts of the diurnal variation of these pollutants and overall ambient air quality of this urban area in different season have been presented in detail. The road traffic was confirmed from the results as a major source of air pollution in the Al-Jahra area.

KEYWORDS- Air Pollution; Al-jahra; Continuous monitoring; Seasonal variations; Traffic.

I. INTRODUCTION

Air Pollution is considered as one of the most serious worldwide environmental concerns, which can be defined as an atmospheric problem, that results in the deterioration of the ambient air quality. This problem is mainly caused by the technical progress and has its associated price of commercialization and industrialization, which strongly affected the ability of the environment to clean itself [1, 2]. Moreover, weather conditions are very important and can affect people and human activities. Because of the irregularly distributed information, Dejmal [3] utilized interpolation methods for the weather phenomena. Conversely, climatic parameters project adverse respiratory health effects due to particulate matters, PM [4].

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There were many studies reported discussing the air pollution status in the state of Kuwait [1, 5-9]. Abdul-Wahab and Bouhamra [10] used a mobile Air Pollution Monitoring Laboratory, (APML) to study air pollution in a residential area of Kuwait, which was affected by road traffic increase at an unimaginable scale. Khan and Al-Salem [11] have reported the influence of continuous hourly monitored primary and secondary air pollutants data in the selective regions of urban areas in Kuwait. They concluded that Kuwait is influenced not only by pollutants discharged from local chemical, petroleum and petrochemical industries, but also by road traffic and other sources, which have to be regulated according to international rules and regulations. Al-Adwani et al., [12] used a mobile APML to monitor the effect of fuel change from leaded to unleaded gasoline containing an additive Methyl Tertiary Butyl Ether (MTBE) on air quality in a typical heavy traffic residential area of Kuwait. They have used a mathematical model to simulate this influence on the ambient air quality. They reported that MTBE–gasoline enhances the degree of combustion, and hence lowers CO and hydrocarbons (HC) emissions. However, it increases the emissions of NOx and particulate matter.

Air pollution in Kuwait like any other country is caused by high consumption of fossil fuel in power plants, motor vehicles, petroleum refineries, petrochemical plants and other industries such as cement, bricks and paints and urbanization. Monitoring the level of pollutants is essential for their control. Therefore, the concentrations of air pollutants in Kuwait are constantly measured and monitored by number of fixed Air Quality Monitoring Stations, (AQMS) belonging to Kuwait-Environment Public Authority (KU-EPA).

The state of Kuwait is located in the northeastern corner of Arabian Peninsula, surrounded by the kingdom of Saudia Arabia from south and west direction and the republic of Iraq from the north and Persian Gulf in the east direction. The land frontiers are 490 km of which 250 km forms the border with the Kingdom of Saudia Arabia in the South and West and 240 km length borders with the Republic of Iraq in the North and West. The total area of the State of Kuwait is about 18,000 square kilometers. Kuwait is a major exporter of crude oil, where the 2.6 million barrels per day (mbbld) mark from 14 oil fields and 21 gathering centers was crossed in 2007. Three major refineries process over a million bbld, situated in the southern part of the country, jointly referred to as refineries belt [13]. On top of that, Kuwait has huge power and desalination plants with capacities of 16,000 MW and 2 million m3/day fresh water, respectively. Moreover, Kuwait has 332 motor vehicles per 1000 people [14]. Therefore, the Kuwait environment is exposed to air pollution augmented by extreme weather conditions, for example, ambient temperatures close to 50 ^{o}C in summer and approaches 1 °C in winter. Kuwait is characterized by a typical desert type of weather with long summers spells with high frequency of dust storms, arid periods, and humid conditions. In the period of summer, the power consumption is increased many-fold due to the necessary requirement of indoor air conditioning; thus resulting into high unlimited emissions of various pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), non-methane (NM-HC), nitrogen oxides (NOx) and particulate matters (PM10).

Air pollution has unfavourable effects to the life in Kuwait, strongly influencing human health as well as animals and plants [11]. Air pollutants, particularly sulfur dioxide (SO_2), NO_2 and ozone (O_3) are imperative threats to plants and living species. Some of the local health reports show that 40% of the patients in one of the main hospitals in Kuwait during the period of August–October 1991 suffered from respiratory problems. A similar account of 4400 paediatric cases reported that about 40% had some form of respiratory disorder. Various publications have also shown that the particulate matters of smoke and dust-less than 2.5 microns, (PM < 2.5μm) pose the greatest risk to health [14]. Statistical analysis indicated that there was a highly significant correlation between the increased concentration of specific pollutants and symptoms of reactive and non-reactive airway diseases reported worldwide [15].

II. Description of the Studied Area

Kuwait map (Fig. 1) shows the location of the Al-Jahra residential area relative to Kuwait city and other urban areas in Kuwait. According to the satellite map for Kuwait, Northern oil fields and major free-ways connecting Al-Jahra with Kuwait city and neighboring countries are major contributors to the air quality in Al-Jahra area.

Figure 1 indicates the major contributor to the air quality of Al-Jahra residential area is emission from the northern oil fields where predominantly wind blowing from Northwest direction transports these pollutants over this residential area.

This work is based on the quantitative analysis of air pollution data reflecting the ambient air quality of Al-Jahra the largest governorate in the state of Kuwait. It is surrounded by the industrial, power and desalination plants with heavy traffic connecting its urban area with the rest of Kuwait city. The air quality data in Kuwait were collected using a fixed AQMS operated by KU–EPA, which measured continuously each 5 minutes the quality data of various pollutants. This monitoring station is in the main shopping complex located above the polyclinic in the middle of the residential area. The sampling site is selected on the basis of availability of power and security and position in the topography of the area.

Al-Jahra area is unique due to its location facing the predominant wind blowing from northwest most of the times throughout the year. It is surrounded by several utility industries, powers and desalination plants, wastewater treatment plant and free-ways connecting it to the rest of Kuwait City. Kuwait municipality's 2003 records describe Al-Jahra as a relatively run down residential suburb of central Kuwait, covering total area (11,230) km2. Al-Jahra has a total population of (269,915), housed in (34,755) residential blocks. The district is situated on the major free-way, 6th ring road at the north end.

However, the main sources of pollutants are the northern oil fields, gravel quarries, free-ways and Power desalination plants and wastewater plants thus provides an important reason for selecting Al-Jahra as a study area is the fact that being a largest, ancient and historical residential suburban site.

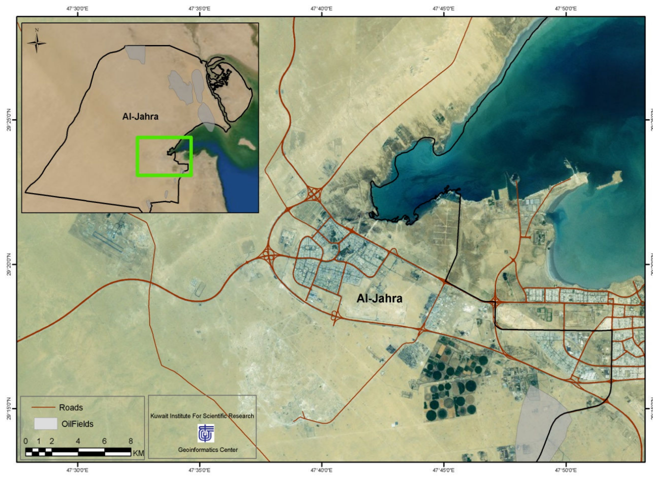

Figure 1: Al-Jahra residential area with respect to neighboring areas in Kuwait city.

Kuwait has only two distinct seasons, harsh summer and light winter, each lasting for almost six months. However, for the purpose of this study, these two representative seasons are broken down further into four periods, namely winter, spring, summer and autumn. These seasons are divided into three months each, starting from winter, which is January to March, followed by spring season from April to June, summer season from July to September, followed by autumn season from October to December.

III. Results and Discussions

In response, the Kuwait Environmental Public Authority (Kuwait-EPA) was established in 1995 as an official agency dealing with legislation for the protection of the environment. Similar to other environmental agencies around the world, the KU-EPA established a number of fixed monitoring stations to form an air quality monitoring network to measure ambient air quality within residential areas. These monitoring stations continuously measure hourly mean concentration of different pollutants. Out of these, studied measurements cover hourly based assessments for major pollutants, include Carbon monoxide (CO), Nitrogen oxide (NOx), Methane (CH_4), non methane hydrocarbon (NM-HC), and Carbon dioxide (CO_2) calculated during the year long period started from January to December 2008 for four above mentioned seasons. The correlation shows a decrease in ozone concentration with an increase in the concentration of Nitrogen oxide (NO_2) and non methane hydrocarbons (NM-HC). Al-Jahra fixed station hourly data cover meteorological parameters such as wind speed, wind direction, temperature and humidity, which are used for evolution of year long period hourly minimum, hourly maximum and daily average values for the assessment of air quality in the selected area.

IV. Carbon Monoxides (CO)

Carbon monoxide (CO), is highly toxic to humans and animals in higher quantities, although it is also produced in normal animal metabolism in low quantities, and is thought to have some normal biological functions. CO is a common industrial hazardous gas generated from the incomplete combustion of natural gas and any other material containing carbon such as gasoline, kerosene, oil, propane, coal, or wood forges, blast furnaces and coke ovens. Internal combustion engine is also one of the most common sources that is responsible of exposure in the workplace. When CO is inhaled into the body it combines with the blood, preventing it from absorbing oxygen. If a person is exposed to CO over a period, it can cause illness and even death.

In the state of Kuwait, CO hourly data are recorded for year 2008 and there is no violation noticed during the whole period of study. It is observed that hourly maximum concentration for winter season is the highest about 9.03 ppm recorded on 19th of January at 21:00 hour as shown in Figure 2. The seasonal average ground level concentration in winter is 0.79 $\pm$ 0.7σ ppm, where standard deviation, σ value is 0.86 ppm. Similarly the hourly maximum concentration for spring season is 4.91 ppm on 12th of April at 18:00 hour (Figure 3). The seasonal average ground level concentration in spring is 0.74 $\pm$ 0.7σ ppm, where σ is 0.74 ppm. Moreover, during the summer season, it is found that hourly maximum concentration is 5.18 ppm on 23rd of September at 00:00 hour (Figure 4). The seasonal average ground level concentration is 1.16$\pm$0.9σ ppm where standard deviation is 0.90 ppm. Similarly hourly maximum concentration in autumn season is second yearly highest about 9.0 ppm, on 19th of November at 09:00 hour and average ground level concentration remained 1.64 $\pm$ 0.8σ ppm, where σ is 1.00 ppm (Figure 5). All seasonal average values are calculated on hourly recorded concentration values.

Traffic congestion and rush hours within city limit and along major highways contribute mainly to the CO levels in the ambient air. The measured CO concentrations for year 2008 have focused very much on pollution near roadsides as prevalent source. Ettouney et al., [5] evaluated the CO air pollution data for Al-Jahra and found the diurnal variations in CO being consistent with the behavior of non reactive photochemical components, observing the extreme values occurring during the early morning and late evening hours. Road transportation is the major source and the relevant contribution from traffic is varying considerably, particularly in peak timing hours in Al-Jahra area. Generally, the highest CO concentrations are reported in the peak traffic congestion times. Through the summer season CO concentration values are not that high due to summer vacations I schools and colleges and residents travelling to hill stations in other parts of the world. Other major factor that controls the CO levels is high temperatures and high wind speed dispersing the pollutant evenly resulting into low values.

Furthermore ambient CO levels are higher in winter due to low temperatures, low planetary boundary layer resulting into low dispersion other than high emissions during cold start. Stump et al., [16] showed cold-start operation of vehicles required fuel enrichment to provide sufficient fuel vaporization for combustion, thus resulting in higher HC and CO emissions. As the engine warms up to normal operating temperature, fuel is vaporized more readily and enrichment is gradually reduced to near stoichiometric levels, thus lowering the HC and CO emissions. It is also noticeable that the contribution from other sources relatively indicated in the measured CO levels reflect the ambient air quality.

The predicted daily ground level concentrations of CO are compared with KU-EPA ambient air quality standards. The maximum allowable level for hourly CO concentration specified by KU-EPA is 30 ppm and for daily concentration of CO is 10 ppm. Close examination clearly indicated that the predicted ground level concentrations of CO are always lower than the specified limits by of KU- EPA, in the whole year. It is not only a harmful air pollutant in itself, but also results in other pollutants. In particular CO is a major constituent for continental and global scale carbon dioxide (CO_2) reacting with oxidizing agent like ozone (O_3), which are important greenhouse gases.

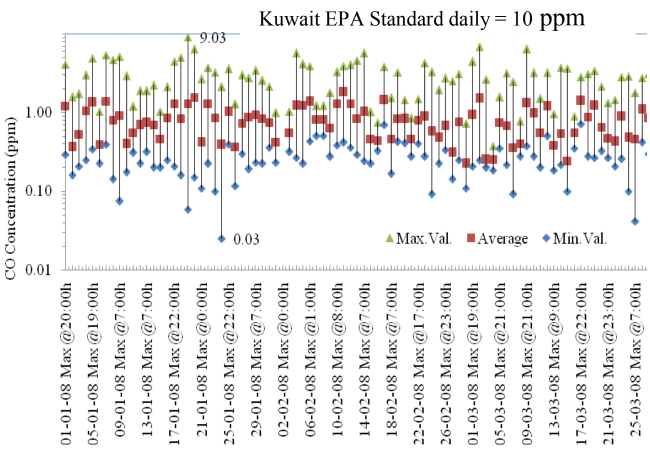

Figure 2: Daily average and hourly maximum CO concentrations for the winter season.

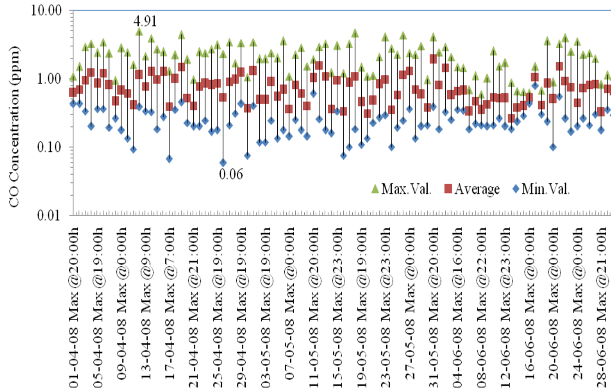

Figure 3: Daily average and hourly maximum CO concentration for the spring season

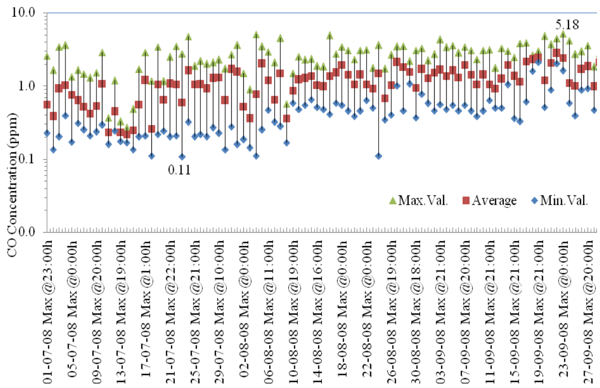

Figure 4 : Daily average and hourly maximum CO concentration for the summer season.

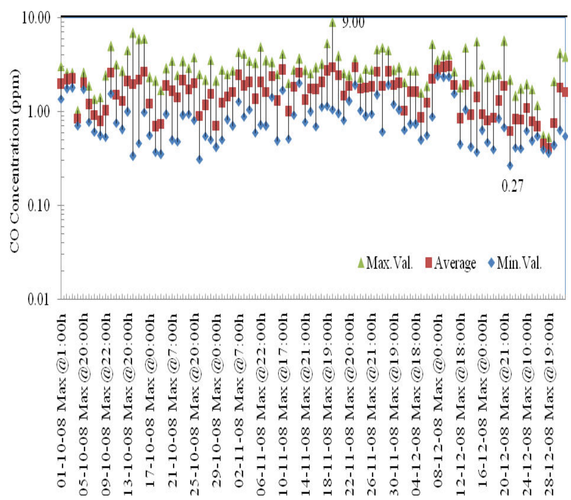

Figure 5: Daily average and hourly maximum CO concentration for the autumn season.

V. Nitrogen Dioxide (NO_2)

Nitrogen dioxide represented as NO2 is a secondary air pollutant; is one of the nitrogen oxide, NOx, combination of nitrogen and oxygen compounds of varying concentrations depending on the oxidization state, generally found abundantly in most urban areas worldwide. They are formed because of combustion processes (mainly when fuel burns at a high temperature) [17]. The variation in the concentrations in the following figures, illustrates the seasonal average concentration with daily mean and hourly minimum and hourly maximum values for Al-Jahra AQMS for the year 2008. These values of NO_2 concentrations reflect pollution levels in residential Al-Jahra area mainly emitted from car tailpipes.

NO2 is oxidized product and either deposited through wet or dry process resulting into nitric acid and hence along with sulfur dioxide plays an active role in the acid rain problems causing smog or dry deposition as particulate matter. Oxides of nitrogen can contribute in the formation of nitrate particles, which are directly proportional to the concentration of NO. Salem et al., [13] studied the air quality in two residential areas in Kuwait, Fahaheel and Mansoriah. They reported diurnal patterns of major primary and secondary pollutants for two years. Similarities were found in typical airborne pollutants associated with both residential areas. NO peaks were in contrast to ozone due to prevalent titration effect. Total hydrocarbon, THC concentrations were associated with emissions strength of different industrial sources. When nitric oxide (NO) reacts with oxidizing agent, like ozone O3, hydroxyl ion OH, to produce NO_2 increasing its concentration. Burning of fossil fuel mainly in power stations and road traffic is the major contributor of NOx emission. Moreover, nitrogen oxides act as one of the precursors in generation of ozone.

Considering the seasonal impact on residential area of Al-Jahra due to the NO_2 concentrations, it is highlighted that during the winter season, hourly maximum concentration recorded is 144 ppb on 25th of March at 19:00 hour as shown in Figure 6. Average seasonal ground level concentration during the winter season is $40.42 \pm 0.9\sigma$ ppb, where the standard deviation, σ is 24.03 ppb. There are 10 times violation equivalent to 1.24 % exceedance observed in this season. The hourly maximum recorded concentration of NO2 is 137 ppb on 27th of April at 20:00 hour (Figure 7). For spring season the average seasonal ground level concentration is $37 \pm 0.8\sigma$ ppb, where the value of the standard deviation, σ is 21.73 ppb. There are 10 times violations resulting into only 1% exceedance in this season. During the summer season, hourly maximum concentration is 145 ppb on 22nd of July at 19:00 hour (Figure 8). Average seasonal ground level concentration $36 \pm 0.9\sigma$ ppb, where the standard deviation, σ is 19.43 ppb. There are 10 violations reflecting overall 1% exceedance in this season. The highest maximum concentration is noticed about 183 ppb in autumn season on 13th of October at 09:00 hour (Figure 8). The seasonal average ground level concentration is $36 \pm 0.8\sigma$ ppb, where the standard deviation, σ 19.17 ppb. There are only a few violations reflecting about 0.23 % exceedance, based on hourly concentration.

The NO_2 is a oxidation product of NO, which requires strong oxidizing agent, like ozone or hydroxyl group. New cars have integrated low NOx technology and had very low emissions of NOx and VOCs. NO_2 concentrations are high during evening time with the exception in the autumn only when the highest value is recorded at 9:00am. Ettouney et al., [5] studied the distribution patterns of NO_2 concentrations for Al-Jahra, and reported gradual increase in NO_2 concentrations annually for the period of four years. There is a strong influence of background concentration of NOx due to many fixed and mobile sources including contribution of population and industrial growth, power generation and associated increase number of motor vehicles.

It is observed that hourly highest NO_2 concentration is 183.17 ppb in autumn season in morning hour while second highest value is 145.25 ppb observed in summer season evening time. There is a noticeable variation in the concentrations of NO_2 between evening and night time during the whole study period reflecting NOx and oxidant concentrations. Changes in traffic patterns influence the NO_2 recorded concentrations at Al-Jahra residential area.

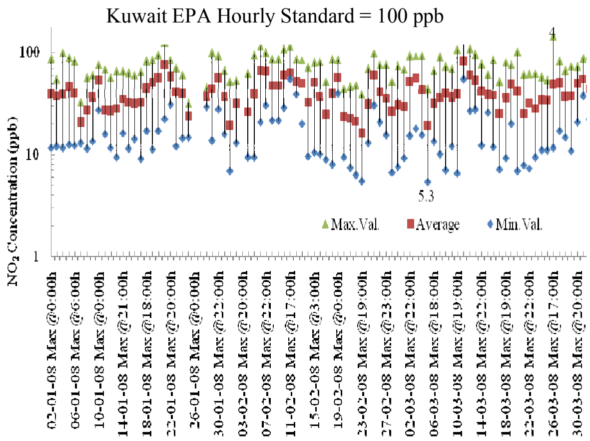

Figure 6: Daily average and hourly maximum NO_2 concentration for the winter season.

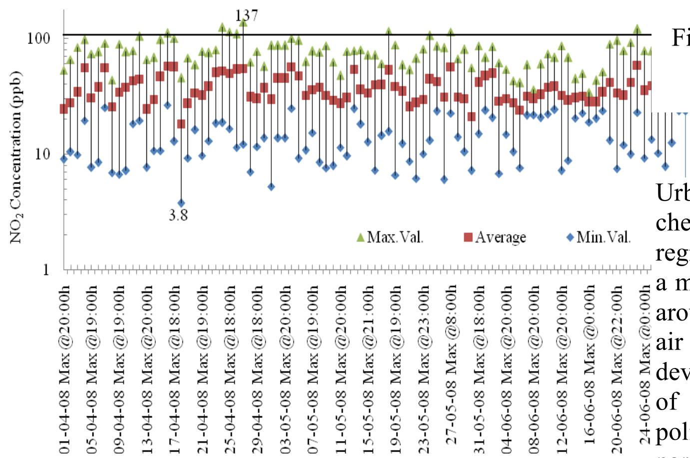

Figure 7: Daily average and hourly maximum NO_2 concentrations for the spring season.

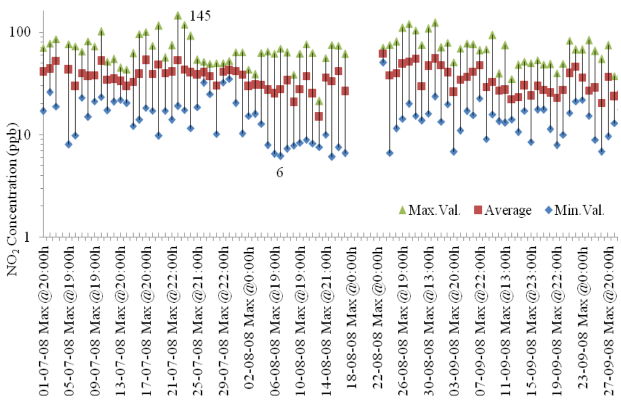

Figure 8: Daily average and hourly maximum NO_2 concentrations for the summer season.

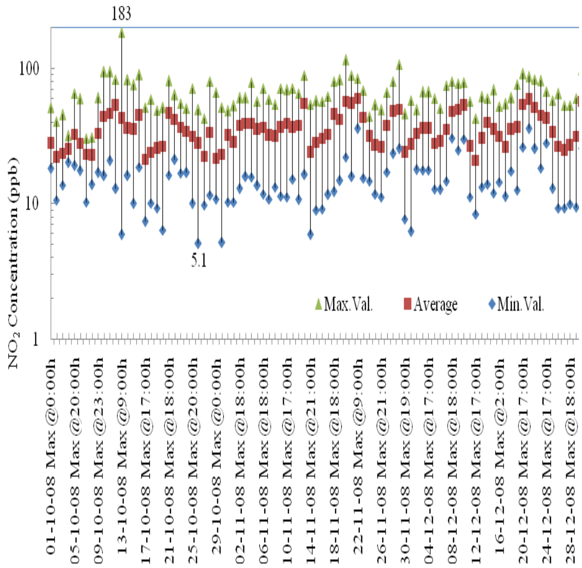

Figure 9: Daily average and hourly maximum NO_2 concentrations for the autumn season.

VI. METHANE (CH_4)

Urban air pollution has a significant impact on the chemistry of the atmosphere and thus potentially on regional and global climate. Already, air pollution is a major issue in an increasing number of mega-cities around the world, and new policies to address urban air pollution are likely to be enacted in many developing countries irrespective of the participation of these countries in any explicit future climate policies. The emissions of gases and microscopic particles (aerosols) that are important in air pollution and climate are often highly correlated due to shared generating processes. Most important among these processes is combustion of fossil fuels and biomass.

Methane comes in particular from human-related sources primarily in the areas of agriculture (livestock and rice cultivation), waste management (landfills, sewage treatment, and manure), and energy (coal and oil/gas production) and many of these allow for cost-effective reduction. Emissions collected from municipal landfills, manure storage sites or coal mines can be harnessed to generate local electricity or upgraded to produce pipeline quality natural gas. Methane warms the planet through a number of direct and indirect effects. CH_4 acts as a potent greenhouse gas, absorbing more long-wave radiation, on a molecule-per-molecule basis, than CO_2. Eventually, CH_4 is oxidized in the atmosphere through a chemical reaction with hydroxyl radicals, producing CO_2 and water. When this reaction occurs in the presence of nitrogen oxides and sunlight, it leads to the formation of ozone molecules in the troposphere another source of radiative forcing, as well as of unhealthy air quality.

In winter season, hourly maximum recorded CH_4 concentration is 4.33 ppm on 10th of February at 11:00 hour as shown in Figure 10. The seasonal average ground level concentration of CH_4 in winter season is 2.05 ± 0.9σ ppm, where standard deviation, σ is 0.29 ppm. Hourly maximum CH_4 concentration recorded is 3.9 ppm on 2nd of June at 14:00 hour (Figure 11). Furthermore average seasonal CH_4 ground level concentration for spring season is 1.87 ± 1.16σ ppm, where standard deviation (σ) is equal to 0.34 ppm. For summer season, hourly maximum observed CH_4 concentration is 5.07 ppm recorded on 8th of August at 22:00 hour (Figure 12). The seasonal average ground level CH_4 concentration for summer season is 2.16 ± 1.3σ ppm, where standard deviation, σ is 0.44 ppm. The hourly maximum concentration is 4.20 ppm on 13th of October at 21:00 hour (Figure 13), with the average ground level concentration in autumn season is 2.31 ± 0.9σ ppm, and the value of standard deviation, σ) is 0.42 ppm.

It is concluded that the highest CH4 concentration 5.07 ppm is in summer season in afternoon time and the second highest value 4.33 ppm is in winter season in morning time around 11:00 hour. Both these values fall around noon time, because methane is generated due to decaying reaction in the presence of heat energy rendered by sun. Hydroxyl ions are also necessary for the oxidation of sulfur dioxides SO_2 to produce sulfates reflecting aerosols that exert a net cooling effect. CH_4 reduces sulfate concentrations, consuming oxidizing agent that may be used in oxidation of methane. The other seasonal highest value 3.89 ppm is recorded in spring season, followed by the other value 4.21 ppm measured in autumn season on 13th of October in late evening. These facts can be justify the location of Al Jahra, which is surrounded by the waste treatment facilities, where decaying of organic matter under anaerobic conditions contributes to the generation of large quantity of anthropogenic methane. It is produced from open sewers and lagoons that emit a substantial share of CH_4 emissions, while industrial wastewater and other waste dump such as food processing and pulp and paper plants also contribute in significant amounts of methane. Moreover landfill's size and age, combined with the quantity of deposited waste determine the level of methane output.

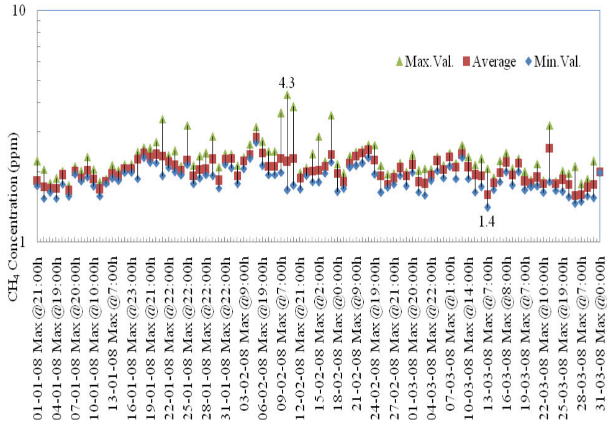

Figure 10: Daily average and hourly maximum CH_4 concentration for the winter season.

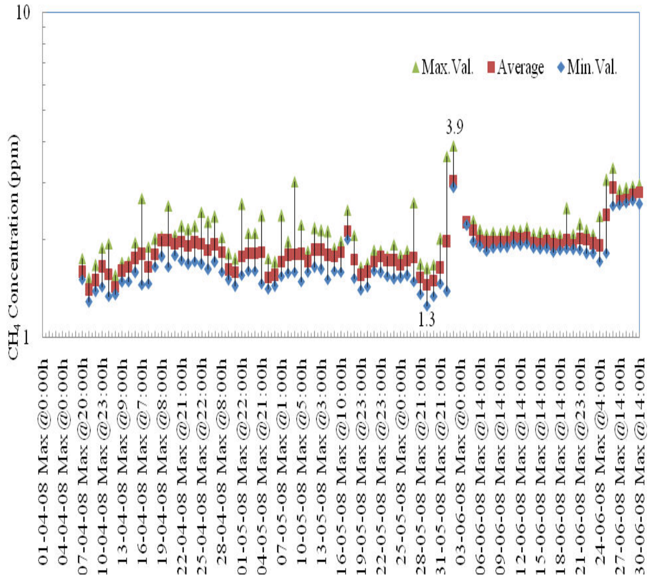

Figure 11: Daily average and hourly maximum CH_4 concentration for the spring season.

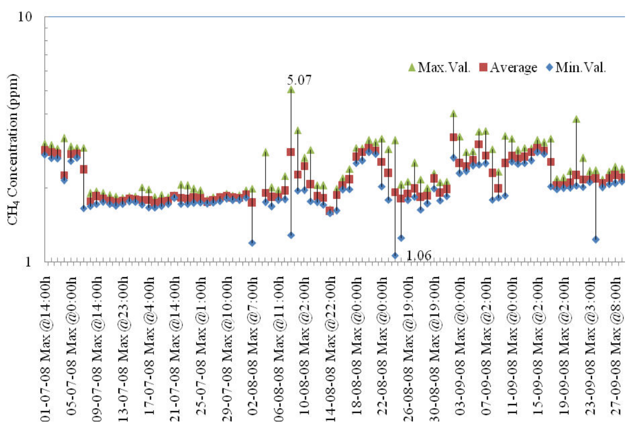

Figure 12: Daily average and hourly maximum CH_4 concentration for the summer season.

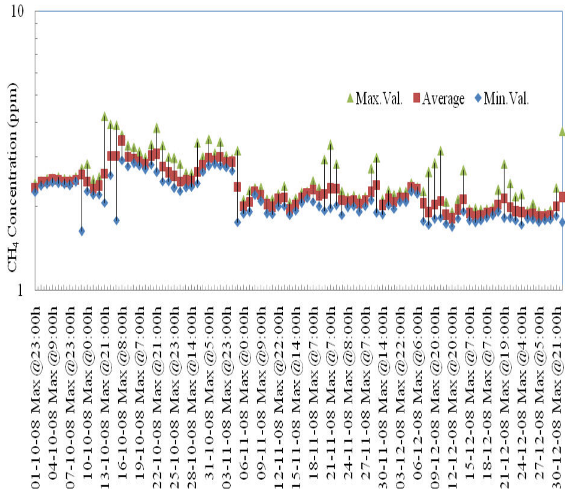

Figure 13: Daily average and hourly maximum CH_4 concentration for the autumn season.

VII. Carbon Dioxide (CO_2)

In winter season, hourly maximum concentration of CO_2 is 912.8 ppm on 19th of January at 21:00 hour. The average seasonal ground level concentration of CO_2 for winter is 326.36 ± 0.7σ ppm, where the value of standard deviation, σ is 58.77 ppm. Hourly maximum concentration of CO2 is 691.2 ppm measured on 21Ist of June at 17:00 hour. The average seasonal ground level concentration for whole spring season is 331.31 ± 0.8σ ppm, where standard deviation, σ is equal to 50.51 ppm. For the summer season, hourly maximum observed CO_2 concentration is 665.2 ppm recorded on 4th of July at 23:00 hour with the average seasonal ground level concentration of CO_2 is 364.9 ± 1.35σ ppm, where the standard deviation, σ is 54.6 ppm. Finally for the autumn season the hourly maximum concentration of CO_2 is 542.8 ppm on 13th of October at 20:00 hour. The average seasonal ground level concentration is 357.8 ± 0.6σ ppm, where standard deviation is, σ = 17.17 ppm.

Balling et al., [18] showed CO_2 is another important pollutant that has been a concern in the state for the last somewhat 20 years. The CO_2 concentrations also show a strong diurnal pattern with lowest values in the mid-afternoon when the local atmosphere is most unstable and highest concentrations in the early evening when the atmosphere becomes more stable and road traffic is high. A secondary peak occurs in the early morning when traffic increases and the atmosphere is most stable. Supporting the fact during the daytime, CO_2 concentrations are related to wind speed and wind direction, with northwestern winds (coming from the desert) dispersing the pollutants resulting into low values of CO_2 concentrations. The values of CO_2 concentrations are correlated with road traffic in Al-Jahra governorate, with low values in the mid-afternoon when the local atmosphere is most unstable and high concentrations in the early evening when the atmosphere becomes more stable and road traffic is high. At night, again the low CO_2levels are associated with high wind speeds.

VIII. Particulate Matters (PM)

Fuller et al., [19] presented the concentration variation of PM10 in an arid country like Kuwait, mainly for the abundance of surrounding sources around the city limits. Road traffic and frequent dust storm are proposed to be essential contributors to the total PM10 ambient load in urban areas. Ettouney et al., [11] showed PM concentrations are related to the meteorological conditions, mainly caused by the surrounding desert. These conditions are aggravated by low rates of precipitation during the short rainy seasons. The maximum hourly concentration of PM is 3824 μg/m3, recorded on 7th of March at 12:00 hours. The average seasonal ground level concentration of PM for winter season is 211.6 ± 0.5σ, μg/m3 where standard deviation, σ is 397.8 μg/m3. There is 24 hours standard for PM10 and the data showed an exceedance of 2.06 %. The maximum value of PM concentration in spring season is 4222 μg/m3 measured on 8th of November at 11:00 hours. The average seasonal ground level concentration of PM10 is 114 ± 0.4σ μg/m3, where standard deviation is equal to 227μg/m3, with little exceedance recorded 0.59 %.

IX. Meteorological Conditions in Kuwait

The meteorological conditions play a predominant role in pollutant dispersion and their respective ground level concentrations in Al-Jahra residential areas. In Kuwait winters are mild and damp, with rains causing further drop in temperature, which falls on occasions to 0 °C during nights. Wind conditions in winters are calm and hence, accompanied with a low inversion layer, which gives rise to the least pollutant dispersion. Spring represents the transition from winter to summer and is the most pleasant season in Kuwait. There is no considerable change in the wind direction, either diurnally or seasonally.

Summer is dry and hot, with maximum day temperatures reaching about 50 °C making it intolerable without air conditioning. Winds are considerably turbulent and are predominantly in northwest direction. This favors effective pollutant dispersion accompanied with a high inversion layer. In autumn, conditions become much more bearable similar to spring.

X. Solar Intensity

The highest maximum hourly value of solar intensity was noticed in spring season about 774.08 w/m2 on 3rd of April at 11:00 hour. Followed by the second highest maximum hourly value 718.75 w/m2 on 7th of March at 12:00 hour has occurred in winter season. The third highest maximum hourly value is 601.17 w/m2 on 7th of July at 12:00 hour, in the summer season. Finally, the hourly maximum value of solar intensity for autumn season is 597.08 w/m2 on 8th of November at 11:00 hour. In Al-Jahra governorate, summer season has high frequency of dusty events, obstructing the solar radiation to reach to the ground. Therefore, the maximum value is in spring season.

XI. Temperature Variations

Because of the harsh weather conditions in the State of Kuwait, the temperature soars up to 50 ^{o}C especially in summer season. The hourly maximum value of temperature 49 oC is recorded in summer season on 26th and 27th of July between 13:00 to 16:00 hours. The average seasonal temperature in summer season is 38.82 ± 1.6σ, ^{o}C where standard deviation, σ is 4.63 ^{o}C. Followed by the second highest value 48.67 ^{o}C is measured in spring season on 28th of June between 14:00 to 16:00 hours. The average seasonal temperature in spring season is 33.78 ± 0.8σ oC, with standard deviation, σ is 6.07 oC. The summer season is characterized by high winds causing severe dust storms that disperse the pollutants resulting into low concentrations. The third highest hourly maximum value of temperature is 40.92 ^{o}C is recorded in autumn season on 11th of October at 11:00 hour. The seasonal average temperature in autumn season is 21.88 ± 0.8σ, ^{o}C where standard deviation, σ is 7.3oC. Finally the spring maximum hourly temperature value is 40^{o}C on 27th of March between 13:00 to 16:00 hours. With the average seasonal temperature is 17.24 ± 0.8σ, ^{o}C where standard deviation, σ is 7.69 ^{o}C.

XII. Wind Speed and Direction

The influence of yearly meteorological data on the measured ground level concentrations of the pollutants is reflected by wind direction and magnitude for a entire period of year 2008. Most of the time, the prevailing wind is from Northwest direction. There is strong influence of the neighboring Persian Gulf, as Kuwait is located at the coast, resulting into strong sea breeze blowing from eastern direction.

XIII. Conclusion

Air pollution and meteorological data for the year of 2008 have been analyzed for Al-Al-Jahra Governorate in the State of Kuwait. The air pollutants considered are carbon monoxide, carbon dioxide, nitrogen oxides, methane, non-methane and particulate matter, as well as meteorological parameters, such as wind speed and direction, air temperature, humidity and solar intensity. Measurements are presented as daily average and hourly maximum concentration for each season for the entire year. Kuwait has arid climate having the highest temperature reaching 50 ^{o}C in summer accompanied by strong northwesterly wind. Winter season is light temperature value is close to 15 ^{o}C. Hourly maximum CO recorded concentration is in winter reflecting inadequate dispersion due to low temperature and low wind speed and shallow planetary boundary layer. Hourly maximum NO2 recorded concentration is in autumn season at 9:00am on 11th October 2008, reflecting oxidation of NO generated due to dense traffic. Hourly maximum CH_4 recorded concentration is in summer reflecting decaying process of organic matter due to elevated temperatures. The high concentrations of different pollutants are noticed in winter season due to prevalent meteorological conditions.

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