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Concentration of NO_2 and SO_2 in Atmospheric Environment Around Oil Refinery: A Case Study in North Khartoum, Sudan, Africa

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Abstract
The environment is considered as man's important asset that must be protected for his life support. Unfortunately, the situation is different where oil refinery and petrochemical plants operate. The aim of this study was to investigate the concentration of NO_2 and SO_2, in atmospheric environment of north Khartoum area as affected by Khartoum oil refinery (KOR) activities. The concentrations of both SO_2 and NO_2 in areas surrounding KOR, recorded high values (0.5, 0.3 mg/m^3) during winter season (October, November, December and January) exceeding WHO and local Sudanese standards, while most of the low values (0.0, 0.1 mg/m^3) were observed during summer season. The highest values of these gases were detected in areas very close to the high way road. Regarding situations of such gases inside KOR plant, in both of winter and summer seasons the highest reading were observed during the years 2013-2015, while during the years 2016-2018, no gases were detected, moreover, for most of the years the highest values(10,9 mg/m^3) were usually observed during the middle and last days of the month. It is so difficult to consider the KOR as only source of the pollutants in area under study since many industrial and traffic activities were present. The study revealed that the government might face a greater challenge in improving the air quality over winter and should pay more attention to reduction of pollutant emission in areas of Khartoum north.
Keywords: Africa air pollution, Khartoum oil refinery, Air quality, NO_2, SO_2

1. Introduction

Over the recent decades, rapid increase in industrial activities, urbanization and traffic movements, in most developing countries, resulted in change of air compositions. Consequently, emissions of air pollutants cause a major environmental problem [1]. As reported by World Health Organization (WHO), over 80% of the world cities have pollution levels exceeding guidelines for safe air [2]. The past decade has seen most countries in Africa grew strongly; this strong economic growth has been matched by the growth of the middle class and the growth of higher levels of disposable income which in turn has led to the increasing investment in creating many of oil refineries [3]. There is great evidence linking air pollution with mortality and morbidity in the general population, damage to public health with adverse effects concentrated in urban areas in Nigeria, broad range of adverse health effects affecting both the respiratory and the cardiovascular system which are observed in both short-term and long-term exposures [4]. The main source of air pollution in the Arabic region such as SO_2, NOx, greenhouse gas emissions and other air pollutants were from oil refineries [5]. Air pollutant concentrations are related to emission rate, atmospheric chemistry, and metrological factors, and also with the time and location [6]. Though refineries and petrochemical industries meet society's energy demands and produce a range of useful chemicals, they can also affect air quality [7]. Oil refineries currently pollute at unacceptable and unhealthy levels. As reported by the U.S. Environmental Protection Agency (USEPA), approximately 22,000 tons of hazardous air pollutants were generated from petrochemical industries [6, 8]. Moreover, studies have shown that actual toxic air emissions from many refinery sources, like flares, tanks, and cooling towers, can be 10 or even 100 times higher than what is reported to regulatory agencies [9]. It was reported that, a closure of oil refinery in Africa eliminates 6000 tons/year of SO_2 emission, with an observed reduction of 20% in wind direction- adjusted ambient concentrations [10]. Oil refineries and petrochemical plants emit many gases like Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO), and ammonia gas (NH_3). Many of the gases emitted by refineries are harmful to human [11], and can cause permanent damage and even death [12]. Also they can cause respiratory problems (such as asthma, coughing, chest pain, and bronchitis), skin irritations, eye problems, headaches, birth defects, and cancers [13]. Petroleum refining and petrochemical industries produce emissions at many stages of the operations. These emissions can significantly deteriorate the air quality and cause short-term and long-term health impacts for workers, and people living near the sites and in the same region [14]. A recently study in France was reported that, 85% of SO2 emissions came from the using of Sulphur-containing fossil fuels, these emissions were release into atmosphere by petroleum refining[15]. The only way the situation can be improved to analyze the process and operations in detail and identify areas where control measures can be taken to reduce these emissions [7, 16]. Air quality in African cities has deteriorated to the owing industrial expansion, it was observed that, oil refineries one were of the main reasons in some areas [17]. A recent review of air pollutants in south Africa observed that the main anthropogenic sources of SO_2 and NO_2 emissions are industries burning dirty fossil fuels in appliance that generally do not have emission control devices. Living in a middle-income country, African countries are simultaneously at risk of ill health related to air pollution that due to normal operation of the oil refineries [18]. To manage potential health impacts of air pollutants, it is important to implement proper air quality management by understanding the link between specific pollutant sources and resulting population exposures [19]. Currently research related to air quality in Africa has been focused on indoor environment. Most studies were carried out inside of the oil refiners' plants. The air qualities in residential areas around oil refiners' plants have not been extensively investigated. There is a clear lack of urgency from African governments in addressing the worsening air quality around oil refineries areas in the region, possibly owing to the absence of reliable data on air pollution levels due to weak and non-existent air quality monitoring networks in the countries. In Sudan very few or no research studies were conducted to evaluate air pollutants emitted from oil or petrochemical plants. Based on above, the main goal of this study is to investigate the effect of refinery on local air quality by taking the residential area surrounding Khartoum oil Refinery plant as study case. The results and conclusions were compared with World health organization (WHO) and local Sudanese standards, and some suggestions were given for governing policies and plans.

2. Methodology

2.1 Area of study

The selected study area is the residential area surrounding Khartoum oil Refinery plant, at north direction near Algeili town in Bahri locality (figure. 1). About 70Km from Khartoum city Centre, in Khartoum state. This state lies between longitudes 32° 31' 56.68" E and latitudes 15° 33' 6.37" N. Khartoum state cover a total area of 22,142 km2 and has a population 5,274,321 inhabitants (2008 census). The selected area of study is near significant ecosystems mainly River Nile. Moreover many industrial activities and free zone area are present in these areas. This examined area was chosen for this study on base of its location on the crossways of the emissions of the refinery. Northeast are the prevailing wind directions in winter (October, November, December and January). During this season, wind speed varies from moderate to strong that caused air pollution in these areas, while during summer season (February to May) the wind is weakling with variable directions (figures 3 and 5).

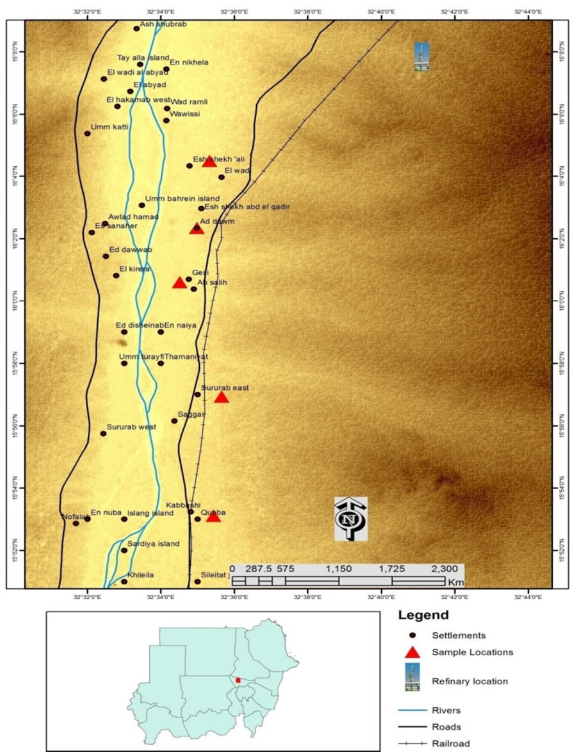
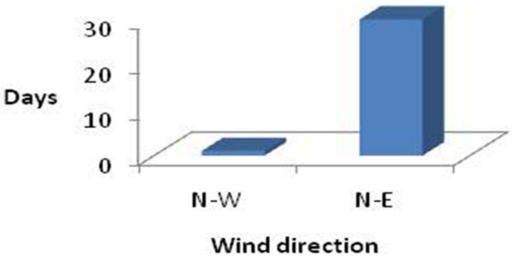


Figure .1 map of Study area and samples location site



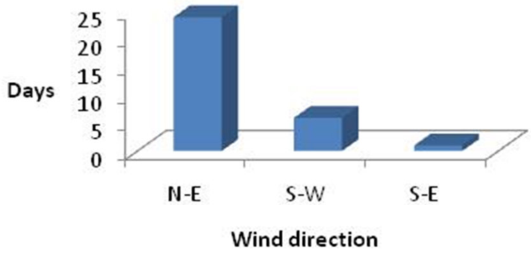


Figure .3 Numbers of day for Wind direction during January 2017 (winter season)

Figure .5 Numbers of day for Wind direction during May 2017 (summer season)

2.2 Sampling strategy and analysis

For the analysis of SO_2 and NO_2 in the atmospheric environment under study area, six locations were selected using GPS program based on their distances from the refinery plant and taking into account of wind direction (0.0 km, 5 km, 15 km, 17 km, 24 km, and 30 km, as First, Second, Third, Forth, sixth ,E and F locations respectively). For analysis of such gases from the second to sixth Locations gray wolf modular monitor: GW-3016 was used as direct reader [20]. This device was handled to reach a position at 1- 1.5 M above the floor level, which was considered as a position that satisfy the requirement of measurements objectives, while For the first location (0.0 km) measurements were taken by the Continuous Ambient Air Quality Monitoring Station (CAAQMS), located inside the refinery plant (KOR) using the environmental monitoring solutions system (ecotech) (Kumar, 2018). Measurements for this location were taken during summer and winter seasons of the years 2013-2018. While for the other locations under study measurements were conducted at afternoon, within a four months period, which covered both winter and summer seasons. Other environmental parameters including air temperature, relative humidity, and wind speed and wind direction were also recorded using KOR monitoring station.

3. Results and Discussion

In order to assess the air quality in Khartoum north areas, particularly areas around Khartoum oil refinery, concentration values of some pollutants were analyzed and compared with the limits and guidelines specified by last regulations of World health Organization (WHO) and local Sudanese standards (maximum permissible limits) as follows.

3.1 Concentrations of Sulphur Dioxide (SO_2) in different locations away from Khartoum oil refinery (KOR) in different seasons

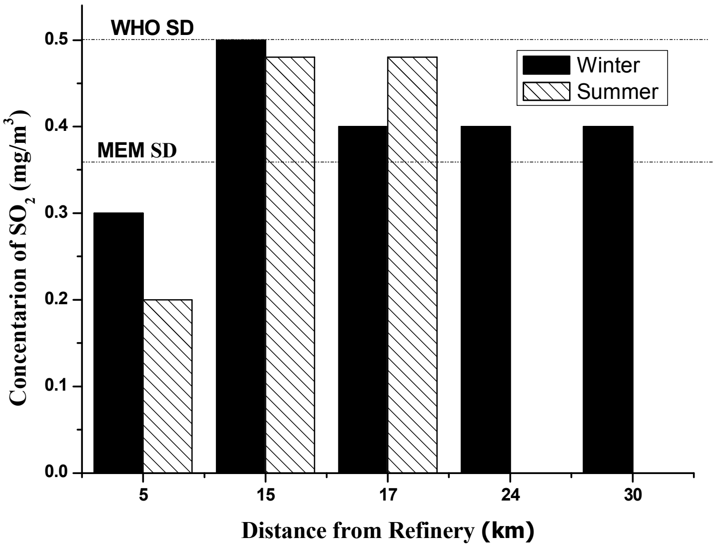


Figure .2 Concentrations of Sulphur Dioxide (SO_2) in different locations away from Khartoum oil refinery (KOR) in different seasons

Figure .2 Summarizes the results of Sulphur Dioxide (SO_2) concentrations detected in different locations selected bases on its distance from Khartoum oil refinery, the results indicated that this gas was generally ranged between 0.0 to 0.5 mg/m³. The maximum values were detected at the third location in both seasons under study (0.48 and 0.5 mg/m³). The results also indicated that, the fifth and sixth locations readings were recorded a zero concentration at summer, that means these areas during summer are not exposed any kind of this gas. it is clear that, the highest concentrations of SO_2 are detected in all selected locations during the winter season, indicating that the seasonal effect is an important influencing factor of local pollutant characteristics in urban environment, which was also observed at all locations. Generally, the main reason for this pattern is the adverse meteorological conditions, including greater atmospheric stability, lower mixing layer height and lower temperature, in winter compared to in summer season [21]. It is well known that, in Sudan during winter season wind blowing from the north (figure 3). As shown in Figure 2. The maximum reading was 0.5 mg/m³, which was detected at the third location of the area under study during winter season. This value is almost in the line of the allowable limit of WHO; however it may cause negative health effects for people who live near this location. The maximum allowable limits set by the WHO for SO_2 is 500 µg/m^3 10-minute (0.5 mg/m³). However this value does not comply with the Local Sudanese Standards, which set SO_2 to be 0.36 mg/m^3 for gaseous emissions resulting from Petroleum Refining [22]. It was observed that, some of the obtained results exceeded the concentration of the 10-minute and this may be very harmful to those resides in these areas therefore a quick action and decision from the authorized sectors is needed. It was also observed that, with exception of second location, during winter season, the concentrations were above the values of the local Sudanese standards. This may be attributed to the fact that, these locations are affected by other source of emissions in addition to the oil refineries. High-emission areas are concentrated in these locations, mainly because the road network structure is more intensive, and the distribution of commercial and residential areas is relatively concentrated in these areas, these locations are close to the high traffic way (Figure 1). Generally, in summer season, the average concentrations of SO_2 comply with the air quality standards of WHO; and local Sudanese standards. One of the reasons for the low concentration of this gas during this season is that, KOR has adopted some control measures such as installation of environmental control unit in purpose to remove the hydrogen Sulfide, ammonia and other gaseous contaminants dissolved in sour water before discharge to sewerage [23]. According to the Sudanese oil quality, it is characterized by having small quantities of Sulphur; therefore it is one of the best oils in Middle East, because Sulphur has harmful impact on the environment. In addition to that, it also characterized by having the specification of the Diesel derivative above sixty octane number which is high enough to raise the burning competence [24]. It was observed that the third, fourth and fifth recorded readings are under the allowed levels according to WHO standards. It is well known that, wind speed and direction are meteorological parameters that play a major role in the distribution of emissions and may vary from day to day [25]. SO_2 concentration decreases when wind speed is high, due to greater dilution. When the predominant wind direction is such that wind carries contaminants from the source to the sampling sites, in this case the concentration observed will be higher, when compared to other wind directions (figure. 3).

3.2 Concentrations of nitrogen Dioxide (NO_2) in different away distances from Khartoum oil refinery during different seasons

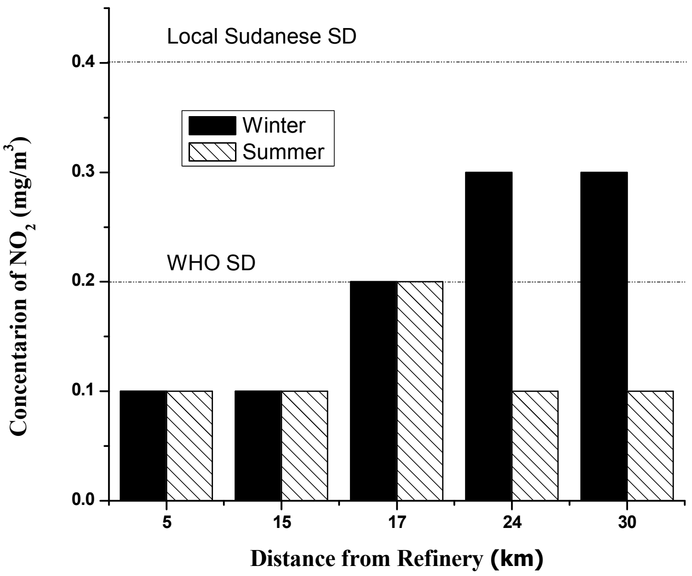


Figure .4 Concentrations of Nitrogen Dioxide (NO_2) in different locations away from Khartoum oil refinery (KOR) in different seasons

The results of NO_2 concentrations detected in different selected locations are shown in Figure 4. These results indicated that, the concentration of this gas was generally ranged between 0.1 to 0.3 mg/m³, with a maximum value at the fifth and sixth locations, under study, in winter season. The concentrations of this gas were safe, because they were below the international and national standard with exception of fifth and sixth locations during winter season. The difference of NO_2 concentrations between the two seasons reflects the effect of the wind direction and wind speed [26], It is well known that, in Sudan during Summer season wind blowing from the south (figure. 5) .Briefly, during summer, the second, third fifth and sixth locations have the lowest NO_2 concentrations 0.1 mg/m^3. The fifth and sixth locations have the highest concentrations for this gas during winter. As the main attraction of Khartoum north area is a focus for the protection of scenic spots. In these areas, water area is vast, vegetations coverage is high. These factors are conductive to the spread and filtration of air pollutants, making the air quality better. It is well known that, Nitrogen oxide is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. Oxygen reacts to form nitrate particles, acid aerosols, as well as NO_2 which also cause respiratory problem. The primary man-made sources of NO_2 include oil refineries, motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. At the second and third locations the concentrations were under the values of local Sudanese standards and WHO in both seasons under study, so that NO_2 emission levels are compatible with those standards and consequently there are no serious levels of NO_2 emitting from the Refinery. In fact, the Nile Blend Crude (Sudanese Oil) contains only traces of nitrogen. Beside oil this gas may stripped from the collected waste sour water at the Waste Water Stripping Unit where it is transformed into NH_3 gas and later mixed with water to form ammonia liquid [27]. Previous study showed that, environmental impacts resulting from air pollutants in residential areas at Khartoum state, the SO_2, NO_2 Concentrations were classified within the local and international allowed limits, the average values of the particulate matter were from 1.11 to 27.78 mg/m³ which exceeds the international limits [28].

3.3 Concentrations of Sulphur Dioxide (SO_2) inside Khartoum Oil Refinery (KOR) during different seasons

3.3.1 Concentrations of SO_2 during winter season

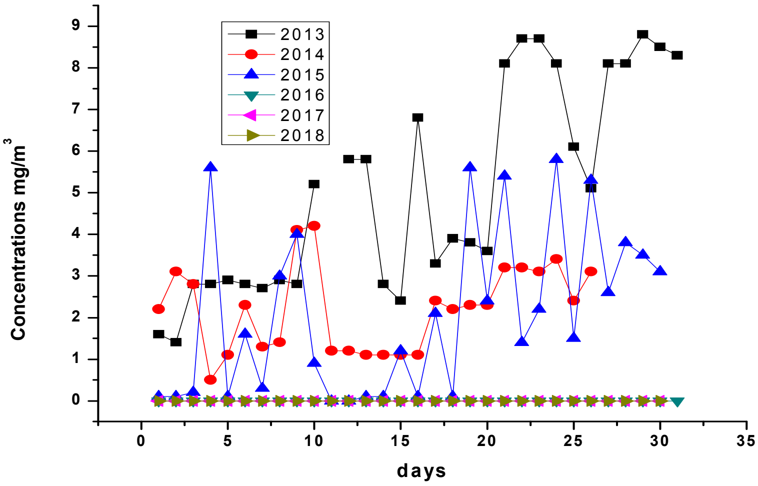


Figure .6 Concentrations of SO_2 during October month for the years 2013-2018

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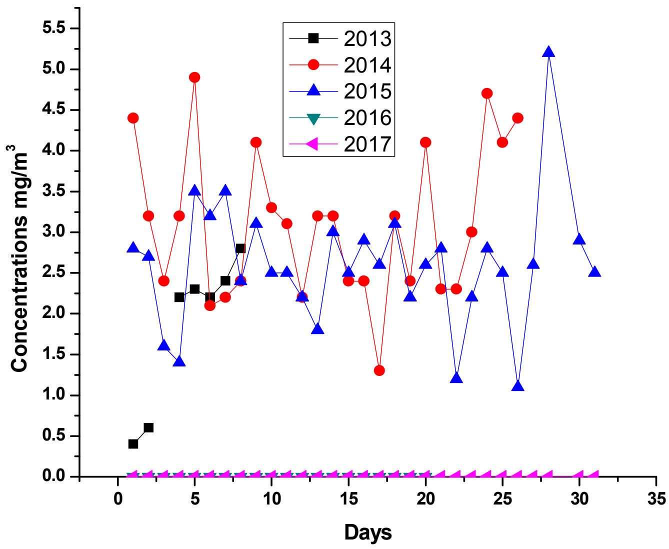

Figure .7 Concentrations of SO_2 during November month for the years 2013-2017

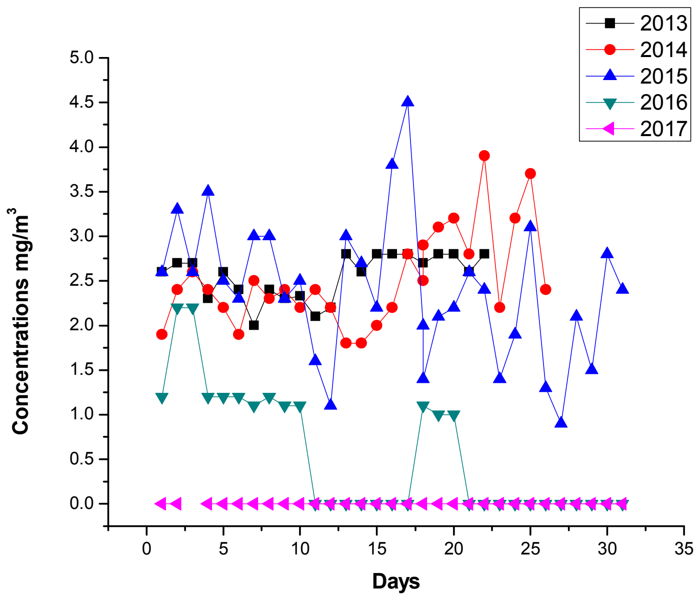

Figure .8 Concentrations of SO_2 during December month for the years 2013- 2017

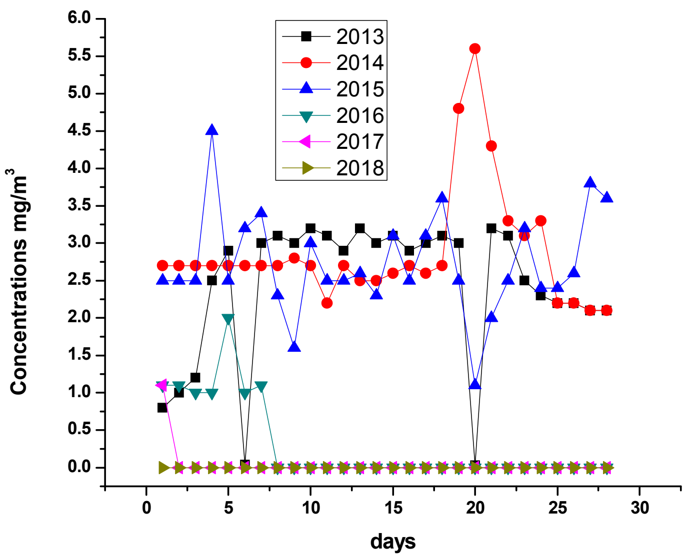

Figure .9 Concentrations of SO_2 during January month for the years 2013-2018

Figures 6,7,8, and 9 illiterate the results of SO_2 measured in side KOR during October, November, December and January months of the years 2013- 2018 respectively. These months represents winter season in Sudan. The results indicated that for October month during the years 2013-2018, High concentrations of this gas were recorded ranging between 0.0- 10 mg/m^3 exceeding permissible limits WHO and local Sudanese standards. The highest values were detected in the year 2013. As shown in figure 7 the result of November revealed that, the highest values for this gas were that of 2014 and 2015, while the lowest values were in years 2017 and 2017. However, these values do not comply with the local Sudanese standards which set SO_2 to be 0.36 mg/m^3 for gaseous emissions resulting from petroleum refining. Also in figure 8, which illustrate the daily pattern of this gas during December, high concentrations were recorded ranging between 0.0 to 4.5 mg/m^3, also the concentrations of SO_2 during January (figure 9), were ranged between 0.0- 5.0 mg/m^3, exceeding permissible limits of WHO and local Sudanese standards.

On the other hand during the years 2016- 2018, for all months of winter season, no gas were recorded, this may be attributed to installation of a refinery environmental unit in early 2016 inside the plant, the main task of this unit is to remove the hydrogen sulfide, ammonia and other gaseous contaminants dissolved in sour water before discharge to sewerage. Moreover, for most of the years the highest values were usually observed during the middle and last days of the month.

3.3.2 Concentrations of SO_2 during summer season

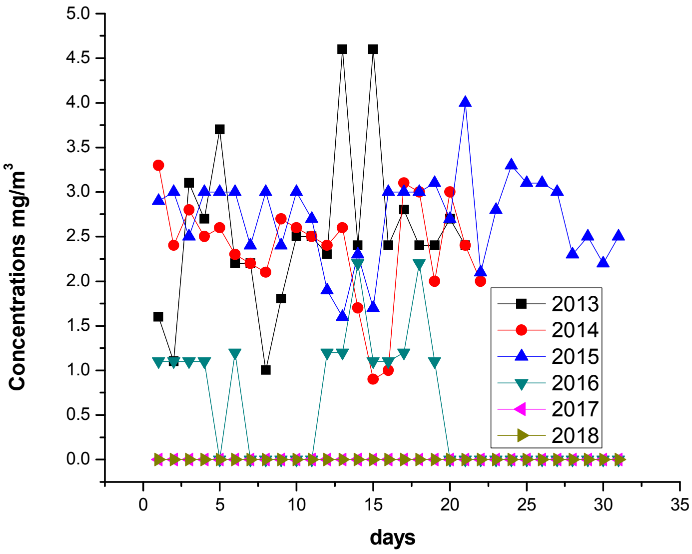

Figure .10 Concentrations of SO2 during March month for the years 2013-2018

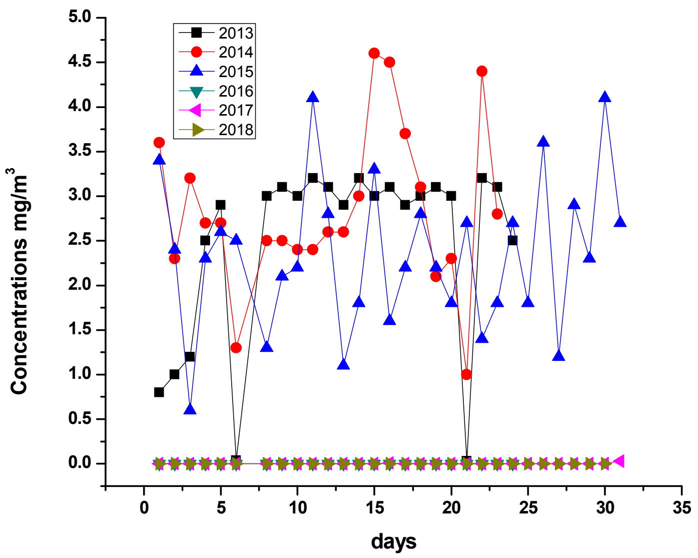

Figure .11 Concentrations of SO_2 during April month for the years 2013-2018

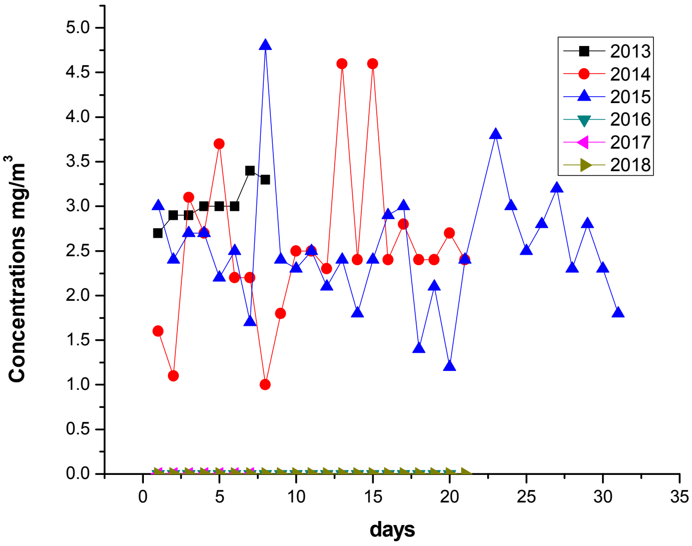

Figure .12 Concentrations of SO_2 during May month for the years 2013-2018

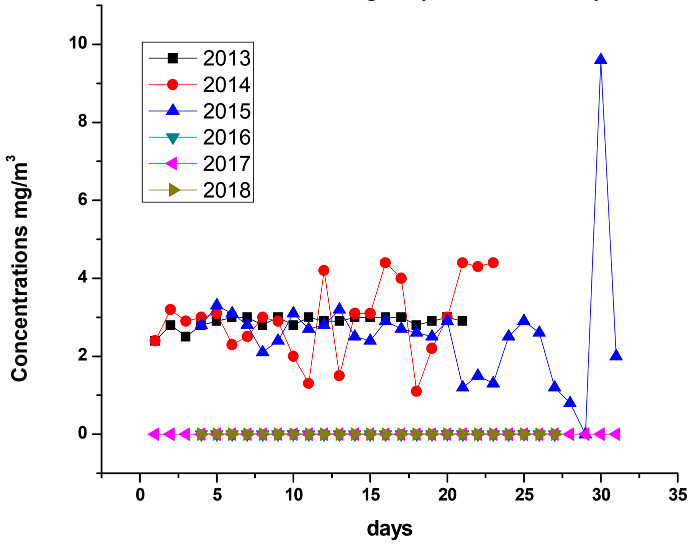

Figure .13 Concentrations of SO_2 during June month for the years 2013-2018

Figures 10,11,12, and 13 illiterate the results of SO_2 recorded inside KOR during summer months, March, April, May and June of the years 2013- 2018 respectively. During March the concentrations levels for SO_2 ranges were from 0.0 to 4.6 mg/m3. During this month high values were recorded in all the years except the 2017 and 2018 (Figrure.10). Broadly speaking, SO_2 levels are comparable or much above than the permissible limits of WHO and local Sudanese standards. It is clear that, the concentrations of SO_2 may contribute to SO_2 levels in all sites around the KOR. While, as shown, in Fig. 11 high concentrations of this gas were recorded in 2013-2015 exceeding permissible limits of national and international standards. The highest values were detected during 2014 with value 4.6 mg/m3. It can be seen that the SO_2 levels were very high during May of the years 2013, 2014 and 2016 (Figure. 12). On middle of the month the concentrations of this gas reached the highest value during the year 2014. It is clear that the background concentrations of SO_2 contribute to SO_2 levels in all sites in area under study. In addition, it was observed that, concentrations of this gas detected during the others months showed similar varying pattern among the period of study. As it was mentioned earlier no gas were detected during the years 2016, 2017 and 2018. For most of the years the highest values were usually observed during the middle days of the month. Concentrations of SO_2 in June for all years between 2013-2018, ranged between 0.0 to 10 mg/m3. On the other hand, it is shown that, SO_2 measured concentrations during the year 2015 is higher than a national and international standard with a highest value which was detected during the last days of the month (Figure. 13). The climatic parameters such as the temperature, relative humidity, wind speed and rainfall have an important effect on the concentration of pollutants in the air and lead a key role in controlling the spread of various air pollutants. The high temperature leads to air movements and the dissemination of pollutants vertically to the greatest extent possible, while the low temperature leads to downward air movements [29].

3.3.3 Concentrations of NO_2 during winter season

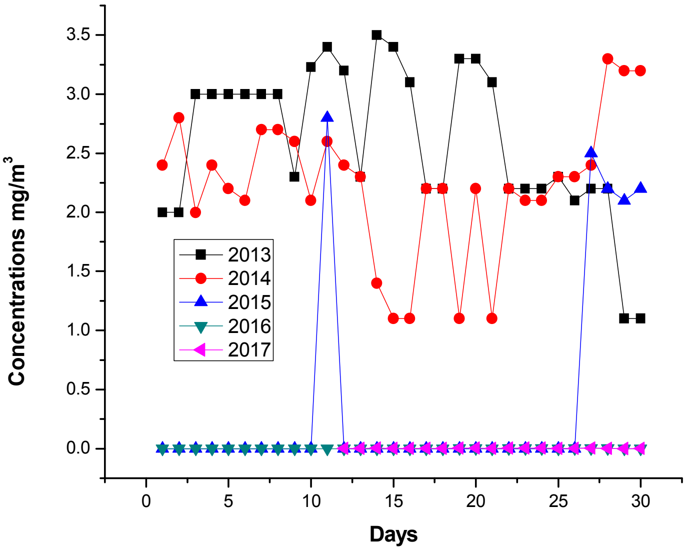

Figure .14 Concentrations of NO2 during November month for the years 2013-2017

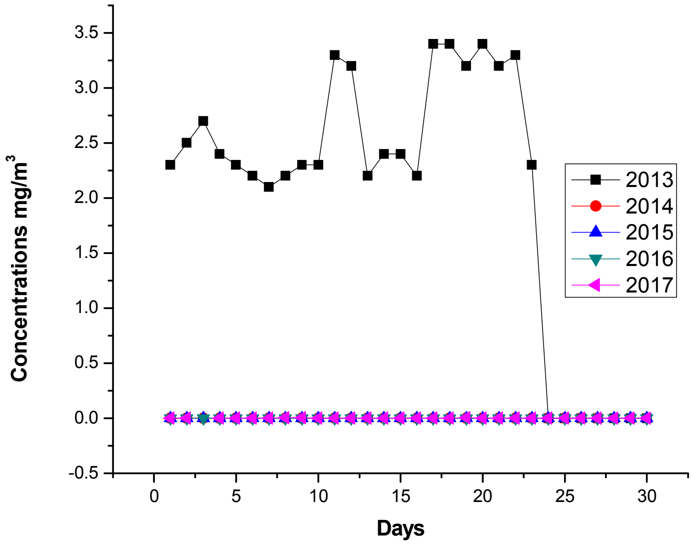

Figure .15 Concentrations of NO_2 during December month for the years 2013-2017

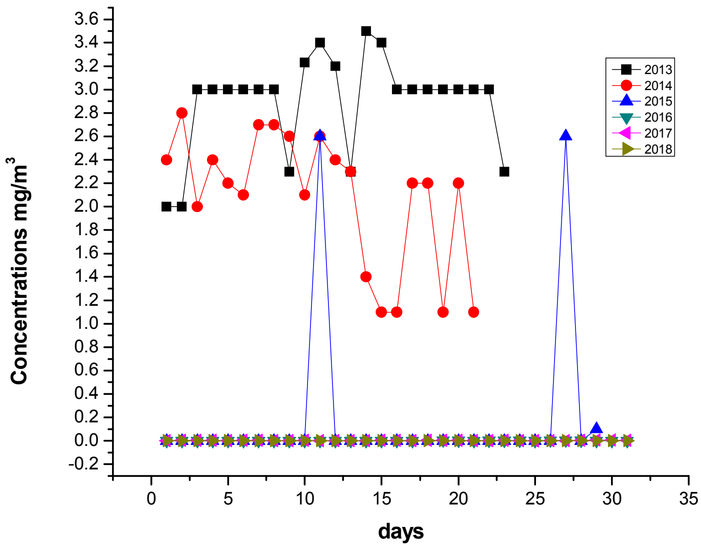

Figure .16 Concentrations of NO_2 during January month for the years 2013-2018

During November, as shown in figure 14, NO_2 exhibit similar seasonal variations as that of SO_2 with lowest concentrations during the years 2016-2017 and the highest during 2013-2014 during the period of study. The lowest NO_2 concentrations 0.0 mg/m3 are found during years 2016-2018 and the highest concentrations 3.5 mg/m3 are observed during years 2013-2016. For December of the year 2013, the concentrations of NO_2 exceeded the standards for the consecutive year (Figure 15). On other hand NO2 concentrations were much lower than the standards during the years 2014-2018 (Figure. 16). Over the entire study period, the concentrations of NO_2 ranged 0.0- 3.5 mg/m3. As shown in fig 16 the result of NO_2 concentrations for January indicated that, high concentrations of this gas were recorded during the years 2013-2014 and a few days of month during the year 2015. It is clear that, concentrations of NO_2 during this month of years 2016-2018 were not exceeded the standard stipulated WHO and local Sudanese standards during the study period.

3.3.4 Concentrations of NO_2 during summer season

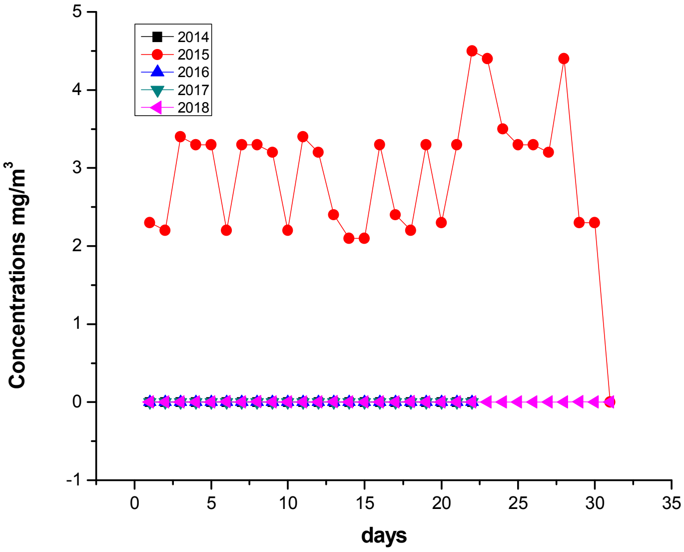

Figure .17 Concentrations of NO_2 during March month for the years 2013-2018

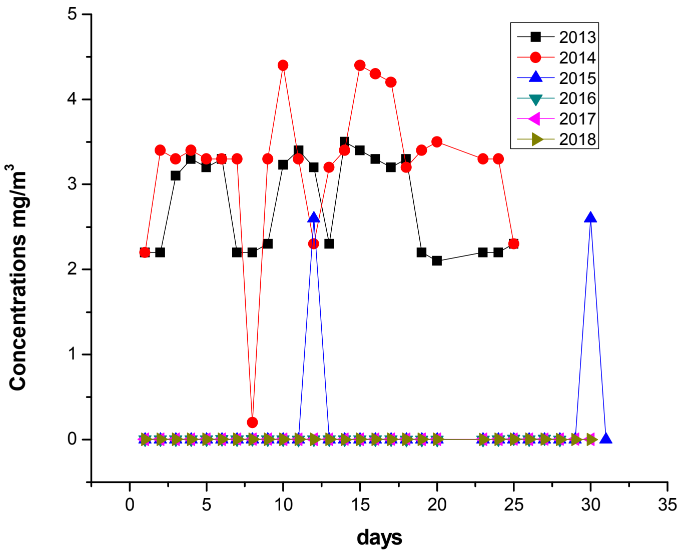

Figure .18 Concentrations of NO_2 during April month for the years 2013-2018

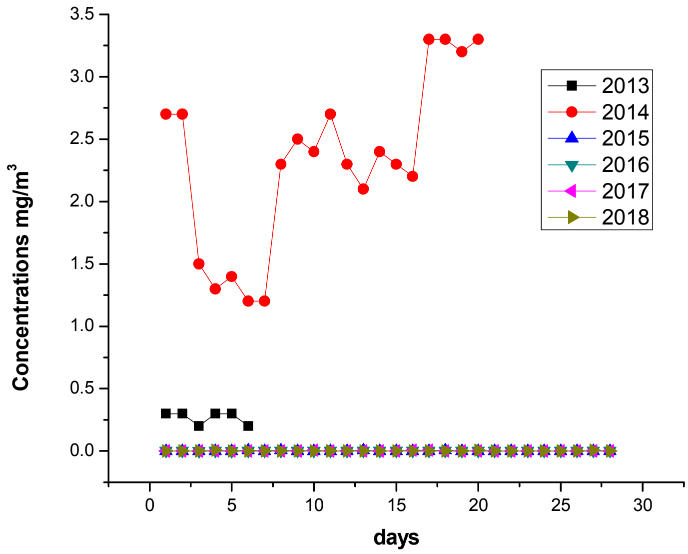

Figure .19 Concentrations of NO_2 during May month for the years 2013-2018

Figures 17,18, and 19 show the results of NO_2 measured inside KOR during March, April, and May months of the years 2013- 2018 respectively, which represents the Summer season in Sudan. Figure 17 clearly shows that the concentrations of NO_2 for March of the years 2013-2018, indicating that, with exceptions of year 2014 the concentrations of this gas were much lower than the WHO and local Sudanese standards. The concentrations of NO_2 during April for the period from 2013-2018,(Figure. 18) Most dramatic increase in the concentrations of NO_2 during years 2013-214 was observed. Zero levels of NO_2 were detected throughout measurements that were only during the years 2015-2018. Figure 19 presents the source of NO_2 during May month. The concentrations level for NO2 ranges from 0.0 to 3.4 mg/m3. The highest concentrations were detected during the year 2014. NO_2 levels are comparable a much above than the permissible limits of WHO and local Sudanese standards. As compared to previous study which was cored out by Khogali (2015), improvement was observed regarding pollution of this environment with both SO_2 and NO_2 gases [30].

Conclusion

Air pollution is something that we cannot really ignore now. the concentrations of both SO_2 and NO_2 in areas surrounding KOR, recorded high values during winter season exceeding WHO and local Sudanese standards, while most of the low values were observed during summer season. The highest values of these gases were detected in areas very close to the high way road. Regarding situations of such gases inside KOR plant , in both of winter and summer seasons the highest reading were observed during the years 2013-2015 while during the years 2016-2018 no gases were detected moreover, For most of the years the highest values were usually observed during the middle and last days of the month. control measures against poor ambient air quality are to be evolved and implemented, Priority locations (from the second to sixth locations). Continuous monitoring shall include all the six criteria pollutants ground level ozone (O_3), Carbon monoxide (CO), Sulfur dioxide (SO_2), Small particulates (PM_{10}), Nitrogen dioxide (NO_2), and the lead (Pb). Additionally CO_2 and volatile organic compounds like benzene the class "A" human carcinogen also need to be quantified. Global attempts to combat air pollution need to attract the support of institutions like World Health Organization, World Bank and United Nations Organization.

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