

Concentration of NO₂ and SO₂ 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 NO₂ and SO₂ in atmospheric environment of north Khartoum area as affected by Khartoum oil refinery (KOR) activities. The concentrations of both SO₂ and NO₂ in areas surrounding KOR, recorded high values (0.5, 0.3 mg/m³) 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/m³) 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/m³) 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, NO₂, SO₂

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 SO₂, NO_x, 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 SO₂ 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 (SO₂), nitrogen dioxide (NO₂), carbon dioxide (CO₂), carbon monoxide (CO), and ammonia gas (NH₃). 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

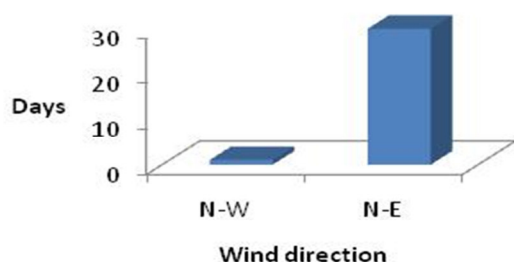


Figure .3 Numbers of day for Wind direction during January 2017 (winter season)

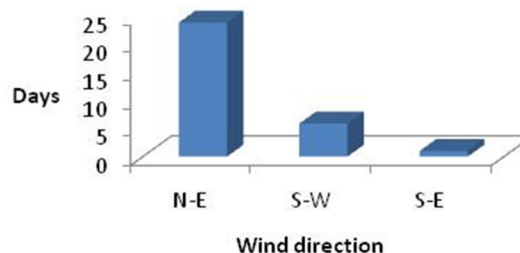


Figure .5 Numbers of day for Wind direction during May 2017 (summer season)

2.2 Sampling strategy and analysis

For the analysis of SO₂ and NO₂ 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 (SO₂) in different locations away from Khartoum oil refinery (KOR) in different seasons

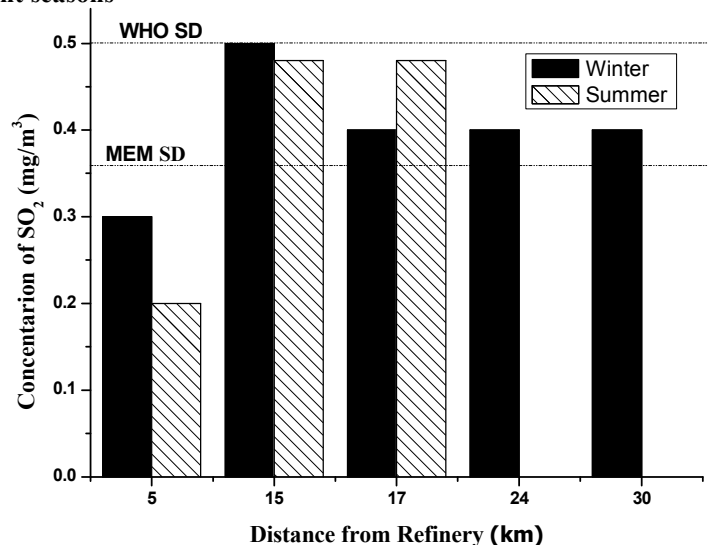


Figure .2 Concentrations of Sulphur Dioxide (SO₂) in different locations away from Khartoum oil refinery (KOR) in different seasons

Figure .2 Summarizes the results of Sulphur Dioxide (SO₂) 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 SO₂ 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 SO₂ is 500 µg/m³ 10-minute (0.5 mg/m³). However this value does not comply with the Local Sudanese Standards, which set SO₂ to be 0.36 mg/m³ 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 SO₂ 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]. SO₂ 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 (NO₂) in different away distances from Khartoum oil refinery during different seasons

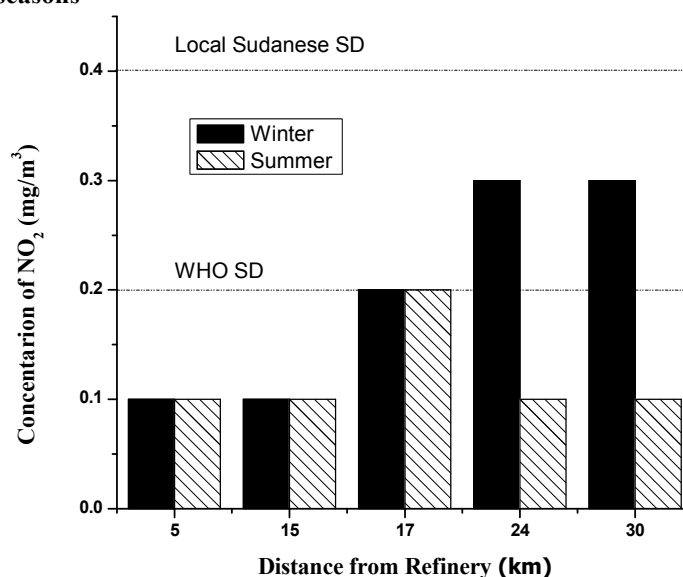


Figure .4 Concentrations of Nitrogen Dioxide (NO₂) in different locations away from Khartoum oil refinery (KOR) in different seasons

The results of NO₂ 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 NO₂ 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 NO₂ concentrations 0.1 mg/m³. 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 conducive 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 NO₂ which also cause respiratory problem. The primary man-made sources of NO₂ 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 NO₂ emission levels are compatible with those standards and consequently there are no serious levels of NO₂ 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 NH₃ 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 SO₂, NO₂ 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 (SO₂) inside Khartoum Oil Refinery (KOR) during different seasons

3.3.1 Concentrations of SO₂ during winter season

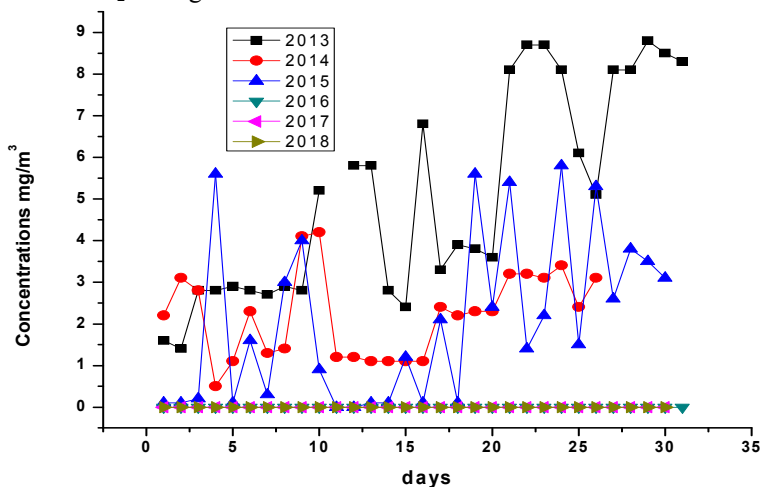


Figure .6 Concentrations of SO₂ during October month for the years 2013-2018

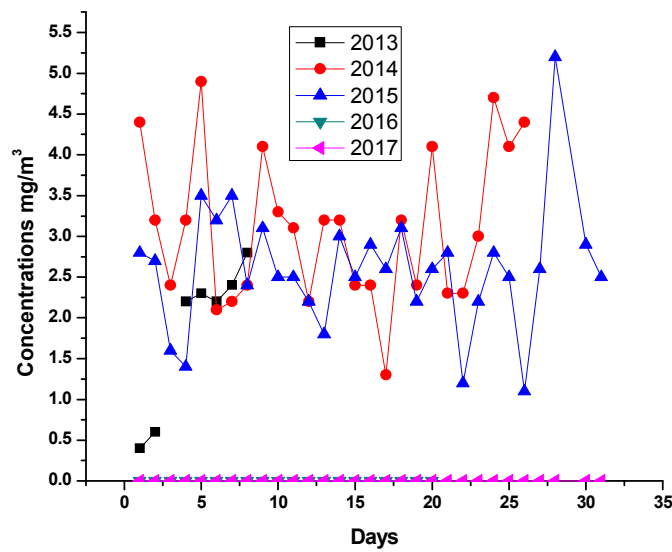


Figure .7 Concentrations of SO₂ during November month for the years 2013-2017

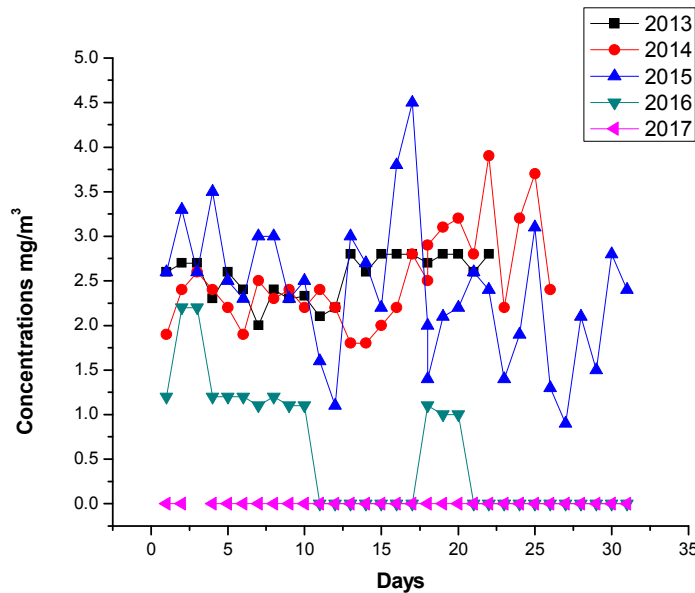


Figure .8 Concentrations of SO₂ during December month for the years 2013- 2017

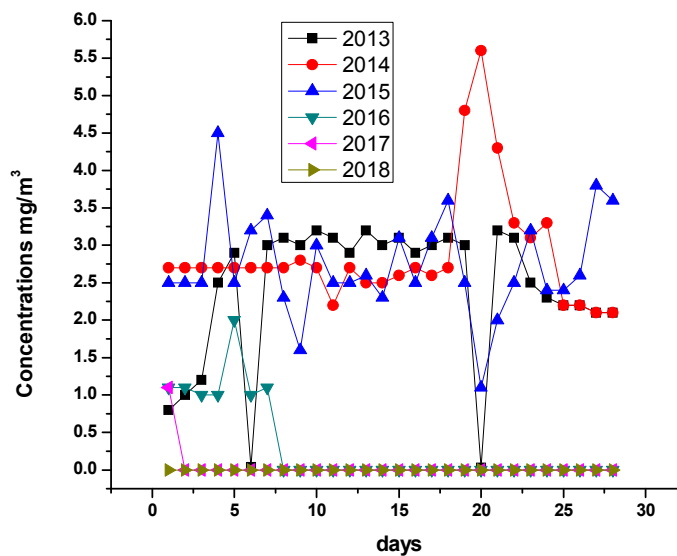


Figure .9 Concentrations of SO₂ during January month for the years 2013-2018

Figures 6,7,8, and 9 illustrate the results of SO₂ 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/m³ 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 SO₂ to be 0.36 mg/m³ 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/m³, also the concentrations of SO₂ during January (figure 9), were ranged between 0.0- 5.0 mg/m³, 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 SO₂ during summer season

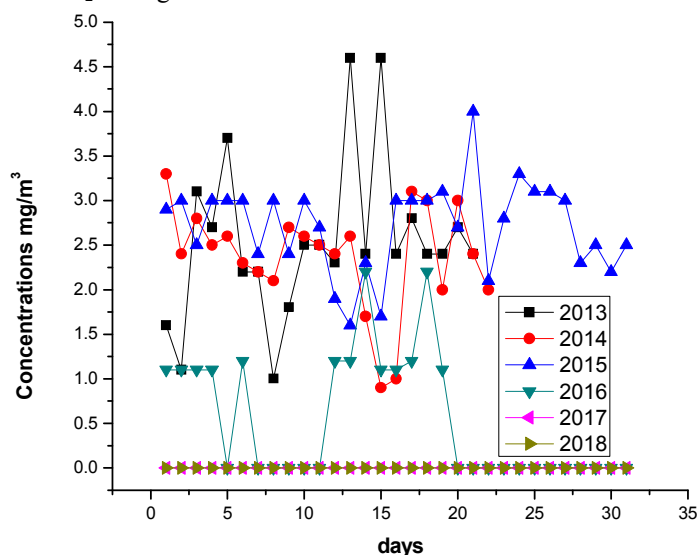


Figure .10 Concentrations of SO₂ during March month for the years 2013-2018

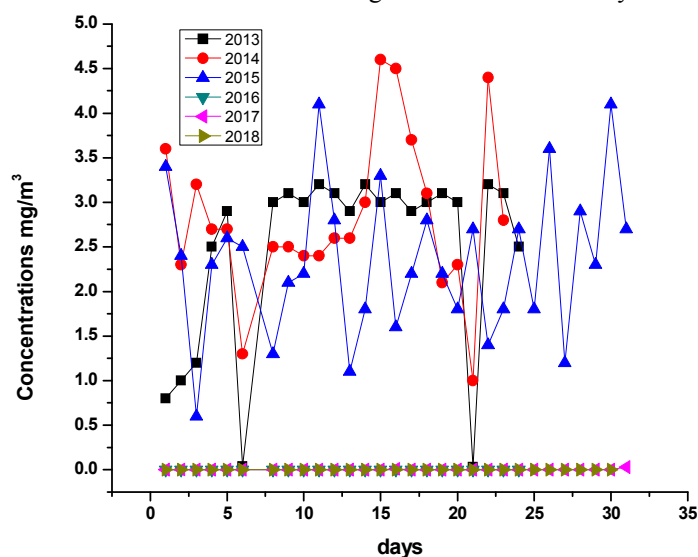


Figure .11 Concentrations of SO₂ during April month for the years 2013-2018

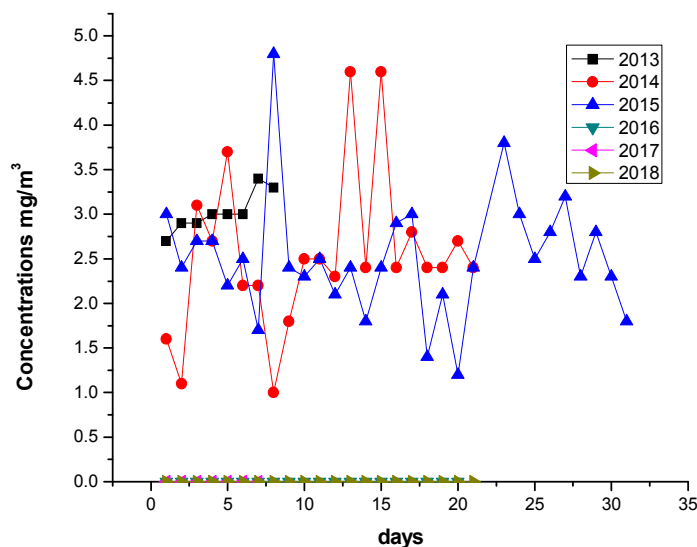


Figure .12 Concentrations of SO₂ during May month for the years 2013-2018

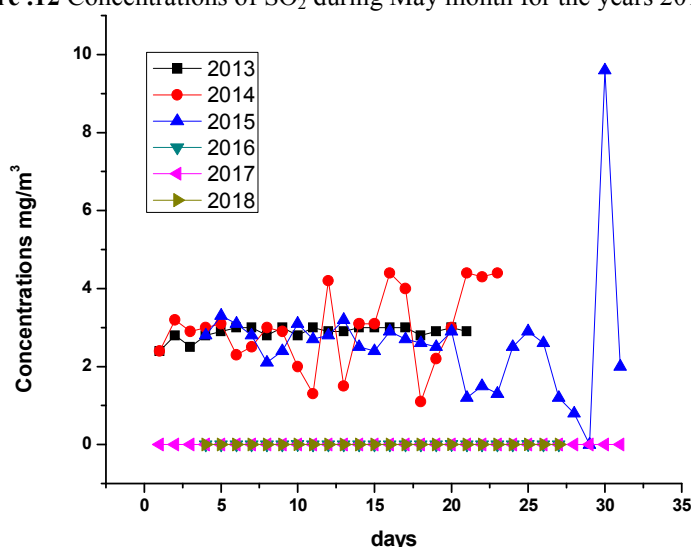


Figure .13 Concentrations of SO₂ during June month for the years 2013-2018

Figures 10,11,12, and 13 illustrate the results of SO₂ recorded inside KOR during summer months, March, April, May and June of the years 2013- 2018 respectively. During March the concentrations levels for SO₂ 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 (Figure.10). Broadly speaking, SO₂ levels are comparable or much above than the permissible limits of WHO and local Sudanese standards. It is clear that, the concentrations of SO₂ may contribute to SO₂ 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 SO₂ 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 SO₂ contribute to SO₂ 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 SO₂ in June for all years between 2013-2018, ranged between 0.0 to 10 mg/m³. On the other hand, it is shown that, SO₂ 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 NO₂ during winter season

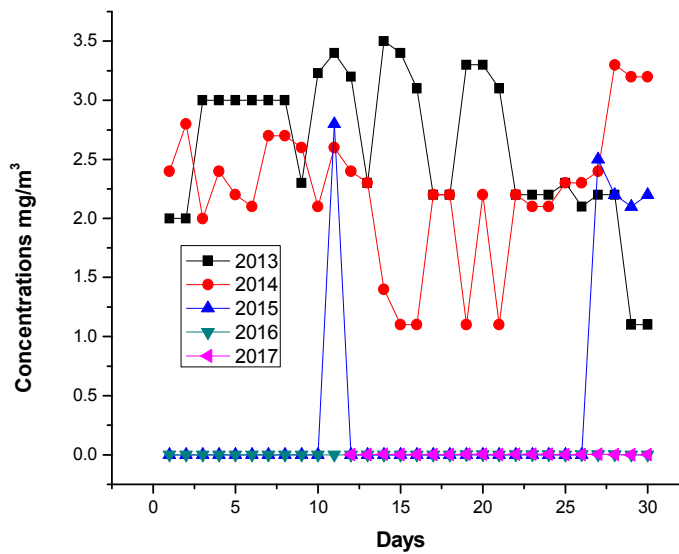


Figure .14 Concentrations of NO₂ during November month for the years 2013-2017

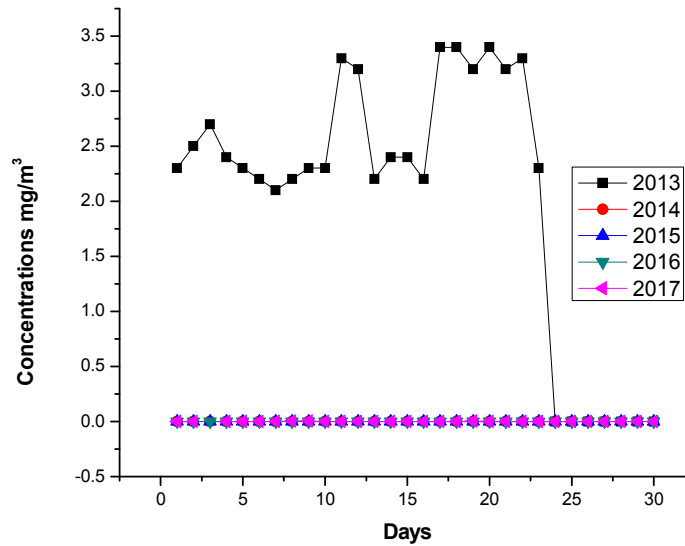


Figure .15 Concentrations of NO₂ during December month for the years 2013-2017

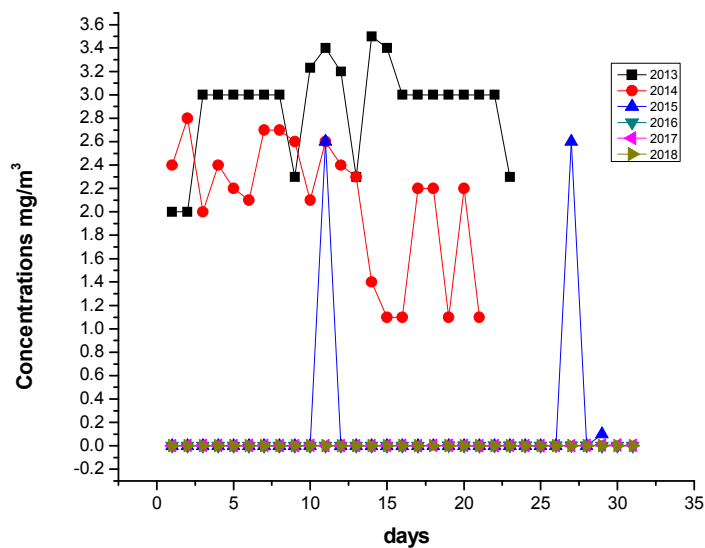


Figure .16 Concentrations of NO₂ during January month for the years 2013-2018

During November, as shown in figure 14, NO₂ exhibit similar seasonal variations as that of SO₂ with lowest

concentrations during the years 2016-2017 and the highest during 2013-2014 during the period of study. The lowest NO₂ 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 NO₂ 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 NO₂ ranged 0.0- 3.5 mg/m³. As shown in fig 16 the result of NO₂ 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 NO₂ 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 NO₂ during summer season

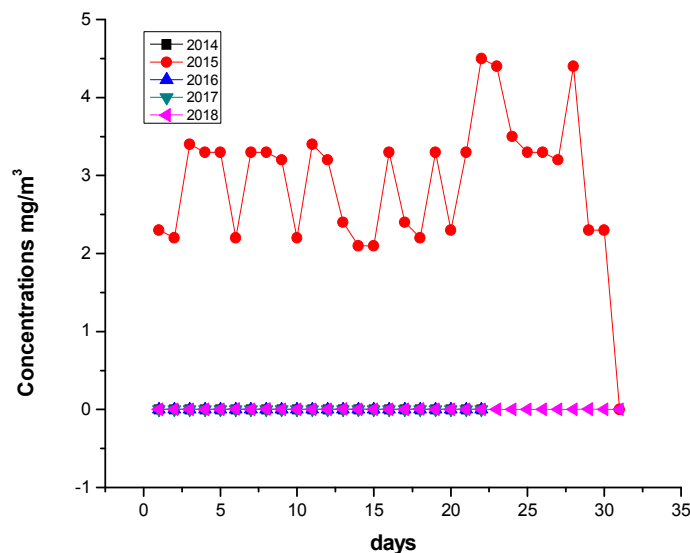


Figure .17 Concentrations of NO₂ during March month for the years 2013-2018

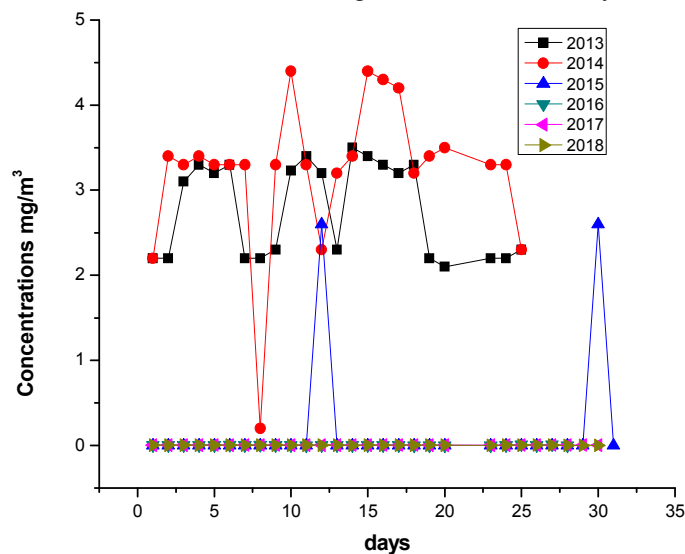


Figure .18 Concentrations of NO₂ during April month for the years 2013-2018

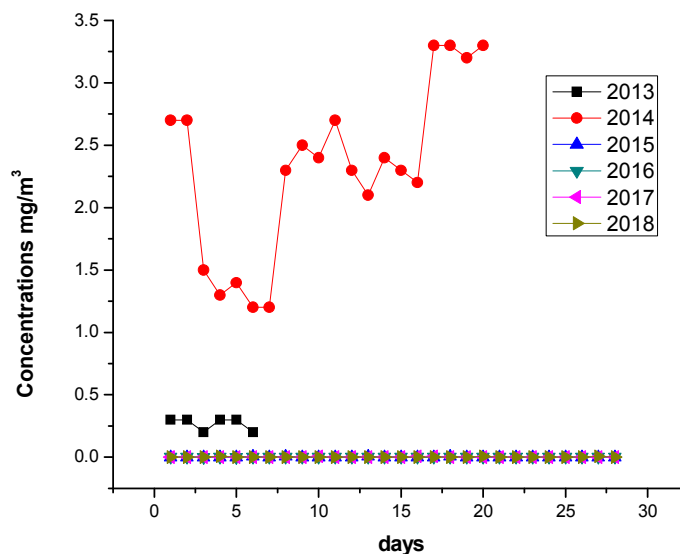


Figure .19 Concentrations of NO₂ during May month for the years 2013-2018

Figures 17,18, and 19 show the results of NO₂ 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 NO₂ 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 NO₂ during April for the period from 2013-2018,(Figure. 18) Most dramatic increase in the concentrations of NO₂ during years 2013-2014 was observed. Zero levels of NO₂ were detected throughout measurements that were only during the years 2015-2018. Figure 19 presents the source of NO₂ 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. NO₂ 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 SO₂ and NO₂ gases [30].

Conclusion

Air pollution is something that we cannot really ignore now. the concentrations of both SO₂ and NO₂ 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 (O₃), Carbon monoxide (CO), Sulfur dioxide (SO₂), Small particulates (PM₁₀), Nitrogen dioxide (NO₂), and the lead (Pb). Additionally CO₂ 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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