



Thermal Power Stations Air Pollution in Khartoum- Sudan

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Abstract

Three air pollutant gases, sulphur dioxide, nitrogen oxide and ammonia emitted from two thermal energy stations at Khartoum North and Garri Oil Refinery at ground level were detected. Parameters measured included ground level concentration, relative humidity, temperature (maximum and minimum) and wind (velocity and direction). Analysis of gases emitted concentration was done according to Adam's 3 Advanced Model and server software package. Passive Diffusion Tubes were analyzed by GC- Ms, IC, and UV spectroscopy. Results showed that sulphur dioxide concentration at ground level ranged 0.78- 9.61 $\mu\text{g}/\text{m}^3$ and 0.29- 3.6 ppb for Khartoum North Power Station (KNPS) while the values for Garri Power Complex (GPC) were also below the limit of detection ranged <0.53 - 1.67 $\mu\text{g}/\text{m}^3$ and 0.20- 0.62 ppb. The values for the concentrations of SO_2 were lower when compared to UK, EU and WHO, 20 $\mu\text{g}/\text{m}^3$ and 50 $\mu\text{g}/\text{m}^3$ respectively while The USA: National Ambient Air Quality Standard (NAAQS) is 80 $\mu\text{g}/\text{m}^3$.

Nitrogen dioxide detected at ground level was 9.69- 29.98 $\mu\text{g}/\text{m}^3$ and 5.05- 15.61 ppb for (KNPS) while 6.92- 33.66 $\mu\text{g}/\text{m}^3$ and 3.60- 17.53 $\mu\text{g}/\text{m}^3$ for (GPC). The values of NO_2 emitted from both power stations were lower than UK, EU 40 $\mu\text{g}/\text{m}^3$ and USA 100 $\mu\text{g}/\text{m}^3$. Ammonia gas was detected at (GPC) which is the main thermal energy supply of (KOR). The highest concentration of Ammonia emitted by (GPC) at 2 Km S distance was 12.736 ppb, 9.03 $\mu\text{g}/\text{m}^3$ and 12.292 ppb, 8.718 $\mu\text{g}/\text{m}^3$ at 2 Km N.

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Similarly high values of concentrations of sulphur dioxide reported for (GPC) at the same distances and wind direction, 2Km S 1.67 $\mu\text{g}/\text{m}^3$ and 2 Km N 1.44 ppb. All of ammonia values reported was below 0.6-0.7 ppm odor threshold. The values of ammonia are lower than USA 20 $\mu\text{g}/\text{m}^3$.

Key words: Thermal power; energy stations; gases; SO₂; NO₂; NH₃; Pollution.

1. Introduction

Human activity in modern world has disturbed the composition of the atmosphere. This as led to some of the major issues of our time, ozone depletion, acid rain and global warming/ climate change which is potentially the most serious [1]. The atmospheric climate change affects both developed and developing countries, but it is more effective in developing countries where ecosystems are vulnerable and majority of the population suffer from droughts, over use of marginal lands and use of biomass for energy. Small changes in climate have adverse effects on crops, grass lands and forests production. The atmosphere is composed of N 78%, O 21%, water vapor (up to 0.002) and relatively small amount of gasses whose presence influences its behavior [2]. The natural green house effect raises the temperature of the planet by 33 OC thus making it habitable. Human activity (anthropogenic) is emitting extra amount of greenhouse gases especially gases: CO₂, CH₄, NO, CFC which change the amount of radiation trapped by the atmosphere results in effect of climate. The increase level of fossil fuel, for heat power generation, transport, industry, intensive agriculture, live stock and poultry production resulted in environmental pollution.

1.1 Environmental pollution

It is any discharge of material or energy into, water, land, or air that causes or may cause acute (short term) or chronic (long term) detrimental to the earth's ecological balance or that lowers the quality of life. Pollutants may cause primary damage, with direct identifiable impact on environment or secondary damage in form of minor disturbance in the delicate balance of the biological food web that are detectable only over long periods [3].

1.2 Air pollution

It is the process in which the substances and energy forms are not present in normal atmospheric conditions. It is the introduction of chemicals (gases), mechanical (particles in suspension), physical (ionizing radiation e.g. ozone) and acoustic (noise).

1.3 Gaseous air pollutant

The author [6] cited by [5] identified three main gaseous air pollutants, sulfur dioxide (SO₂), oxides of nitrogen (NO_x = NO+ NO₂) and ozone (O₃). Gaseous air pollutants can either be primary emitted directly from the source to atmosphere such as gases of power generating plants or secondary from as a result of reactions between primary and secondary in the atmosphere such as ozone [5]. Similarly NO₂ reacts with water in the atmosphere to form nitric acid or sulphur dioxide and water to form sulphuric acid (acid rain if pH is less than 5.7). Generally gaseous pollutants travel far from their points of origination.

1.3.1 Sulphur dioxide (SO₂)

It is a colorless primary pollutant gas with a pungent suffocating odor. It is a dangerous air pollutant, corrosive to organic materials and irritant to the eyes, nose, and lung [4]. It is the 16th most abundant element of 260 ppm [7]. The majority of it exists as sulphates e.g. gypsum (Ca SO₄.2H₂O). All organic fuels (oil, coal, natural gas) contain sulphur. Sulphur content in fossil fuels range between (0.1%- 4.0percent S) in oil, oil by- products and coal and up to 40% in natural gas [8] (when immediately extracted from the well: however, the sulphur is efficiently removed during the processing of gas before distribution [9]: therefore combustion of natural gas is not a major source of sulphur emissions [10]. Khartoum Oil Refinery (KOR) has low sulphur content (0.116-0.250% S).

- Sulphur dioxide emissions:

Sulphur dioxide is a primary pollutant which is emitted into the atmosphere due to the combustion of oil or gas for energy production in electric generation plants, refining, industry, extraction of fossil fuel and domestic use. Thermal electrical generation plants are the main emitters of sulphur dioxide.

- Effects of sulphur dioxide emissions:

Sulphur dioxide found in the air contributed to acid rain, destruction of plant, aquatic life, reduction of forest and agricultural yields besides its effect on human. EEA reports [11] stated that it aggravates asthma and can reduce lung function and can inflame the respiratory track. It can cause headaches, general discomfort and anxiety.

- Sulphur dioxide ambient air quality standards:

EEA report [11] stated that sulphur dioxide pollution limit should be 350µg/cm³ for a maximum of 24 hours or 125 µg/cm³ for a day. While EPA limit is 85µg/cm³ (0.03 ppm) annually.

- Sulphur dioxide pollution control:

Sulphur dioxide and nitrogen dioxide are often lumped together in air pollutant control because of the similarity between them; hence their control will be presented together.

1.3.2 Nitrogen dioxide

It is the thirty fourth most abundant element twenty parts per million (ppm) [7]. Most of the world Nitrogen present in the atmosphere as inert gas constituting 78.05% of dry air besides Oxygen (21%) [12].The gases forms of Nitrogen oxides are (NO₂, NO, N₂O, NH₃, NH₄⁺) [3]. The principal air pollutants of N are NO and NO₂. Although N₂O is not an air pollutant but it might be a contributor to global warming. NO is a colorless gas while NO₂ has a reddish brown color and distinct odor. Small amount of NO is emitted directly to the atmosphere, while the rest of NO₂ is a secondary forming NO₂ in the atmosphere due to reactions. On the other

hand NO is a primary constituent of the major emitted pollutant gas and forming acid rains and secondary in combustion. Scientists classify the NO in combustion gases as thermal prompt e.g. readily inflammable by an internal factor (interaction between N and O in presence of an active hydrocarbon) or an external heating factor e.g. a lightning bolt in the atmosphere [13].

- Anthropogenic sources of NO emissions:

The author [5] stated that the road transport (motor vehicles) was by far the largest contributors of NO emissions compared with very small road emissions of sulphur dioxide. Other sources are energy production, electric power generation, petroleum refining, industry and production processes.

- Effect of NO₂ emissions:

EEA report [11] showed that exposure to NO₂ is associated with increase all-cause, cardiovascular and respiratory mortality and morbidity. NO₂ and SO₂ react with other elements in the atmosphere forming acid rain which pollutes lakes, rivers, ponds and destroying aquatic life. NO₂ emission damage building surfaces and contribute to smog formation.

- NO₂ ambient air quality standards:

EEA report [11] stated that the NO₂ pollution limit for human should be 200µg/m³ for one hour or 40µg/m³ annually while the limit of NO₂ pollution value of USA (NAAQS) is 100µg/m³.

1.3.3 Ammonia air pollution

Ammonia is produced as a result of combustion, mainly from the use of fossil fuels and incineration of waste material. These sources generally result in direct emissions of ammonia into the atmosphere [16]. Other sources come from internal combustion of engine. Agriculture specially live-stock and poultry are responsible for 94% of ammonia emitted in 2008 in Romania. Reduction in live-stock number resulted in reduction ammonia emission and pollution [3]. Ammonia is a colorless gas with very sharp odor it dissolves easily in water and evaporates quickly. It contributes in acidification and acid rains. It does not stay long in the environment. It reacts with other nitric acid to form particles of ammonium nitrite and with aerosols to form ammonium aerosols. The odor threshold of ammonia is 0.6- 0.7 ppm. Czechoslovakia and USRR cited by [NAPA] report stated that ambient air quality standard for ammonia in Czechoslovakia should be 100 µg/m³, and 200 in USRR. Air quality standards for ammonia concentrations have not been established in the United States. Measurements of environmental concentrations indicate average levels of approximately 20 µg/m³ [16].

- Sources of ammonia:

Natural sources as noted by the authors [17] cited by [16] stated that 3.7 X10⁹ tons of ammonia are released into atmosphere annually while 4.2X10⁶ tons are emitted to the atmosphere. The ammonia is produced commercially as a by-product in manufacturing of chemicals.

- Effect of ammonia pollution:

The National Air Pollution Control Administration (NAPCA) report [16] and the author [3] stated that ammonia in high concentration is toxic for both human and animal and can cause death. It is corrosive to the mucous membrane, eye, respiratory tract and throat.

- Ambient air pollution standards:

The (NAPACA) report [16] showed that the average environmental concentration of ammonia is approximately $20\mu\text{g}/\text{m}^3$.

1.3.4 Control of air pollution

Air pollution in developing countries dated back to the years when coal was used as source of energy, heating, transport by road and trains. The main air pollution was due to sulphur dioxide emissions when fuel oil and natural gas was introduced to industry and transport, coal pollution decreased. increased use of high sulphur containing fuel, increased transport facilities and industry brought pollution back to the international concern. The author [15] stated that China and USA are the world's biggest pollutants.

China announced a national implementation of a national emission scheme in 2017 and encouraged more power generation from renewable sources. USA and China intended in their previous commitments to cut emissions and made clear that a new level of ambition needed if December's 2015 critical climate change talks in Paris are to be successful [15].

- Control SO_2 , NO_2 and NH_3 air pollution:

Air pollution and pollutants control depends on selection of sites of thermal plants, refineries, industrial complexes and intensive live- stock and poultry production in relation to urban settlement. The wind direction and velocity should be taken into consideration. Fuels non-pollutant or low sulphur content and high stacks should be used.

- Increase awareness of citizens of environmental of air pollution of SO_2 , NO_2 , NH_3 and others on their impact on human, animal health, aquatic life and environment.
- Decrease dependence on thermal generation and increase hydro- electrical, renewable sources of energy (solar, wind). Use of new efficient technologies.
- Regular assessment of pollutants concentrations to secure that they are within permissible levels.
- Monitoring of CO_2 emission of transport means (car, busses, trucks, heavy duty machines) and imposing pollutant- certified rules.
- Setting and imposing air pollution rules and legislations.

1.3.5 Thermal power plants

They are the power plants in which the prime mover of steam driven. Different fuels are used fossil, coal, low and heavy sulphur fuel and gas. About 30% of electrical power generation in the Sudan is thermal while 70% hydro- electrical. In developing countries thermal generation constitute 60% as reported by [18].

Thermal Power Station is the main sources of SO₂ and NO₂ air pollution. Two thermal plants were selected in Khartoum North industrial area, the first is Khartoum North Plant (KNPS) and the second within Khartoum Oil Refinery (KOR), Garri Plant Complex (GPC). Different distances and wind direction were chosen to represent urban, rural and farming areas. Information on SO₂, NO₂, and NH₃ emissions and pollutions are lacking.

The objectives of this research are:

- Surveying of the two areas (KNPS and GPC) for detecting SO₂, NO₂ and NH₃ and preparing topographic pollution and emission map which can be repeated in similar areas of thermal plants, refineries, industrial and intensive cattle, poultry production areas.
- Measurement of ambient air quality standard in urban centers, rural and farming areas at different distances from the source of emission.
- Assessment of impact of SO₂, NO₂, and NH₃ emissions and pollutions on human health and environment.
- Suggestion of control measures, rules and legislations for gaseous air pollutant (SO₂, NO₂, CO₂ and NH₃).

2. Material and Methods

2.1 Khartoum North Power Station (KNPS) location

- It is located on the eastern side of Khartoum North industrial area, 6 Km NE of Khartoum city centre across the Blue Nile which is 3.5 Kilometers away. It consists of two 33 MW units heavy fuel oil (HFO), two 60 MW units HFO, two 18 MW (gas) and two 25 MW. The total generation capacity of it is 180 MW.
- KNPS is using HFO (2.4- 3% S imported, local fuel oil (LFO) of (0.05- 1% S) from El Obeid refinery and heavy coal from (KOR).

2.2 Garri Power Complex (GPC)

- It is located at 32° 49' E, 16° 13' N at a distance of 70 Km NE of Khartoum Sudan capital 32° 32' E and 15° 32' N. GPC lies within (KOR). Topography is smooth, 404- 410m above sea level. The rock in the area is Gneiss and Granite, the superficial deposits consist of clay, sand and gravel. Maximum temperature 100°F (38°C) prevails February up to November. The average maximum is 94° F (34° C) the remaining two months; sand storms (Haboobs) are common from May to August. Mean annual rain fall is 6.2' (175.5 mm). GPC is 13 Km East of the Nile.
- Duct height thirty meters, diameter 3 m.
- Temperature of outlet 150° C (combine cycle).

- Temperature of outlet 560° C (single cycle).
- Fuel, local diesel oil (LDO) and liquid petroleum gas (LPG).
- Velocity of emission 40000 g/s.

2.3 Sampling

- Passive Diffusion Tubes (PDT) Technique was used to collect emitted gas samples over an extended period by means of diffusion of the gas molecule into chemical absorbent and subsequently and analyzing it. Each tube is ready to use, includes and in line filtered to prevent ingress of particulate matter during exposure and air tight container for storage. Finally all tubes for selected gases were analyzed by GC/MS, IC, and UV spectroscopy at Gradko International Laboratories in UK and certified analyses results were recorded.
- Adams 3 advanced models were used which is a practical dispersion model that simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. The model takes into account of buildings, terrain and coast line on dispersion. The author of this research had been given license number by Adams, A01.0816.R.A.D 300 SU Server software package for editing contour map for this research work.
- The plan of sampling was two intervals for KNPS and GPC as follows:
 - PDTs for SO₂ and NO₂ were distributed in the two study areas (KNPS and GPC) each site Location was investigated through 6 monitoring points being fixed 2 Km in direction (S, SW,N, E, NE, W) and at 4, 6, 9, 12 Kms downwind dominant wind direction, the starting point was the 90 m height stack (KNPS) and the parallel to the height to the eight ducts of Garri Power Complex (GPC).
 - PDTs for ammonia (NH₃) were used only at (GPC) to investigate (NH₃) emission from the nearby KRT Refinery.
 - All PDTs were fixed in monitoring points at a minimum height of two meters above the ground level on Bamboo poles.
 - Collected PDTs samples were forwarded immediately to Gradko Laboratories in UK for analysis.

3. Results

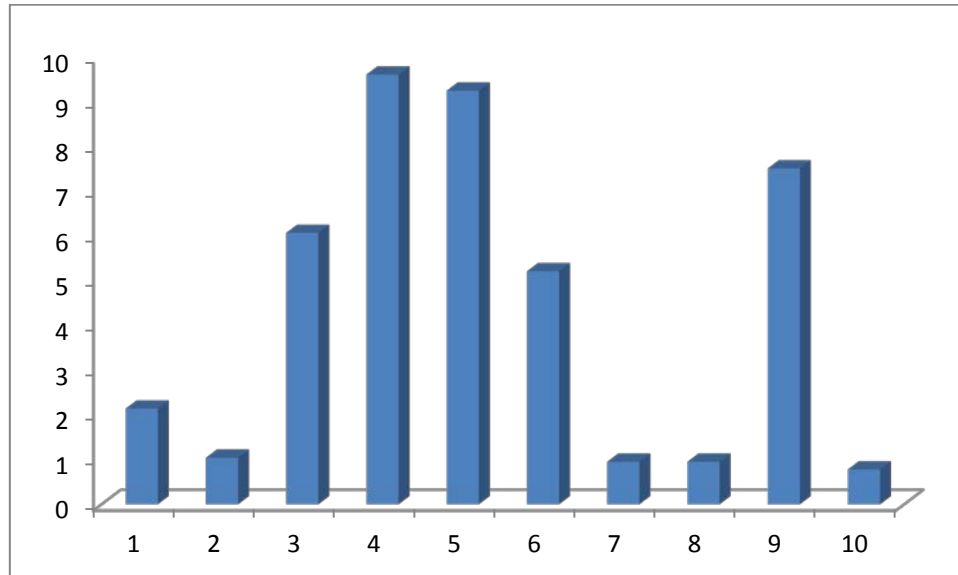
- The SO₂ emissions and concentrations of KNPS are presented in table (1) and figure (1). Analysis was carried out according to what was documented in – House Laboratory Method GLM.

Analysis was carried out according to what was documented in – House Laboratory Method GLM1 Sulphur dioxide had been classified by the author [6] as one of the most gaseous pollutant which has a serious impact on human and environment. It is both primary and secondary air pollutant. The highest concentration of emitted SO₂ from KNPS was 9.61 µg/m³, 3.6 ppb 2Km NE and 2.14 µg/m³, 0.80ppb. The concentration of SO₂ carried by winds at 12 KM away were 9.25 µg/m³ 3.47 ppb ;7.51 µg/m³, 2.82ppb and 1.04 µg/m³,0.39 ppb.

Table 1: Sulphur Dioxide Ground Level Concentration ($\mu\text{g}/\text{m}^3$) – (KNP area) Passive Diffusion Tubes Analysis Results using Dionex ICS 300 Chromatography

Sampling period	sample No.	sample location	Exposure time (hrs.)	Concentration in $\mu\text{g}/\text{m}^3$	ppb	World Bank guidelines	USA (NAAQ0)
10/07/06	9	2Km NE	201	2.14	0.80	80 $\mu\text{g}/\text{m}^3$	80 $\mu\text{g}/\text{m}^3$
18/07/06	10	12KmNE	201	1.04	0.39	Annual	0.03ppm
	11	2Kms	201	6.07	2.28	Mean	Annual measures
	12	12Kms	149	9.61	3.60		
	13	12Km	149	9.25	3.47		
18/07/06	59	2Km	149	5.21	1.93		
	61	5Km	149	0.95	0.36		
	62	5Km	149	0.95	0.36		
	63	12Km	149	7.51	2.82		
		2Km	149	0.78	0.29		

N.B Results are blank subtracted due to high blank Lab Blank: 0.013 Limit of Detection: 0.059 microgram SO_4



1= 2Km NE; 2=12Km NE; 3= 2Km S; 4= 2Km NE; 5= 12Km NE; 6= 2Km S; 7=5 Km SW; 8= 5Km SW; 9=12 Km NE; 10=2Km S

Figure 1: shows (KNPS) – SO_2 $\mu\text{g}/\text{m}^3$ ground level concentrations for different locations

The monitoring of air pollution (SO_2 and NO_2) at 2KM S of KNPS was designed for measuring its effect on Kafori Residential Area (KRA). KRA is located close to KNPS south, south and east south Khartoum North

Power Station and Industrial Area. It lies north and west of the heavy traffic roots.

The concentrations of SO₂ 2KMS (Kafori Residential were 6.07 µg/m³, 2.28 ppb; 5.21 µg/m³ 1.93 ppb and 0.78 µg/m³, 0.29 ppb.

El Saffia Urban Area (SUA) which lies 5Km SW of Khartoum North Power Station was selected for the measurement of SO₂ and NO₂ air pollution. El Saffia lies close to Khartoum North main traffic roads. SO₂ pollution of El Saffia 5Km SW was) 0.95 µg/m³, 0.36 ppb. The low value recorded due to the fact that El Saffia Area is far away from Khartoum North Power Station SO₂ air pollution.

The results of Garri Power Complex (GPC) are presented in table (2) and fig. (2). The results showed a very low SO₂ emissions and concentrations ranging from non detectable up to 1.67µg/m³, 0.62 ppb at 2 Km S; 0.7µg/m³, 0.26 ppb and 0.65µg/m³,0.20 ppb 2Km NE. A concentration of 1.44 µg/m³, 0.54 ppb was recorded 2 Km N. SO₂ concentration of 0.53 µg/m³, 0.2 ppb was noticed at 6 Km NE (farming area). No SO₂ pollution was observed at 2 Km SE. The low values of SO₂ emissions and concentrations of GPC thermal plants are due to the low S content fuel (0.116- 0.250% S) of KOR and Liquefied Gas Fuel (LGF used).

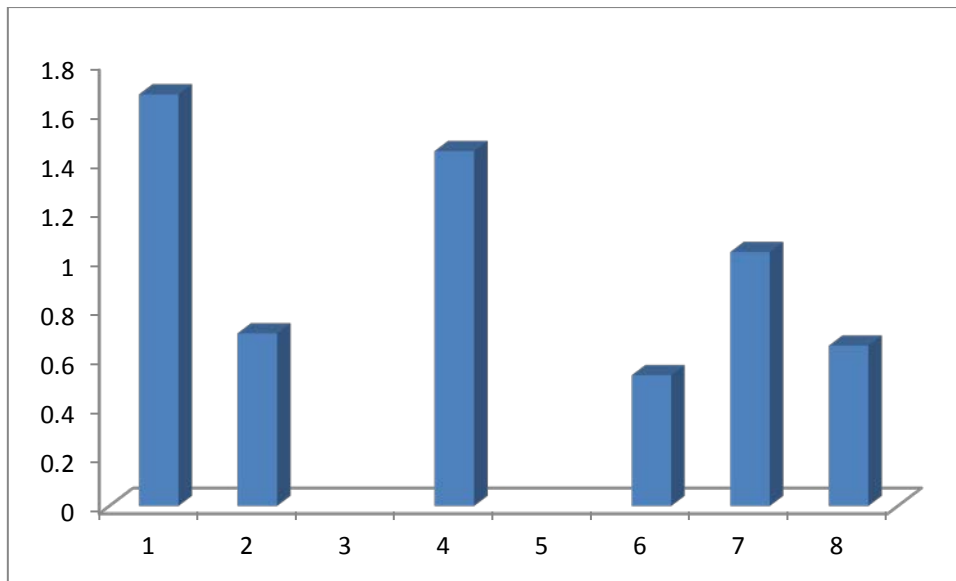
The SO₂ emission in the thermal stations (KNPS and GPC) range from non- detectable up to 9.61 µg/m³, 3.6 ppb are lower than UK, EU and WHO 50 µg/m³; World Bank Guide lines and National Ambient Air Quality Standard (NAQS), 80 µg/m³.

Table 2: Sulphur Dioxide Ground Level Concentration (µg/m³) Garri Power Complex (GPC) Passive Diffusion Tubes Analysis Results using UV Spectrophotometry (UV S003 Cecil)

Sampling period	sample No.	sample location	Exposure time (hrs.)	Concentration in µg/m ³	ppb	World Bank guidelines	USA (NAAQ)
19/07/06	41	2Km NE	144	1.67	0.62	80 µ/m ³	80 µ/m ³
25/07/06	43	2Km NE	144	0.70	0.26	Annual mean	Annual measures
	44	6Kms NE	144	L.O.D	< L.O.D		
25/07	90	2Kms N	152	1.44	0.54		
	91	2Km SE	152	L.O.D	< L.O.D		
	92	6Km NE	152	0.53	0.20		
	93	4Km NE	152	1.03	0.39		
	94	2Km NE	152	0.65	0.20		

L.O.D. means below limit of detection

- The results of NO₂ emissions and concentrations of Khartoum North Power Station is presented in table (3), figure (3). Oxides of Nitrogen (N_x= NO + NO₂) are classified by [6] as one of the three types of gaseous air pollutant. NO is a primary pollutant when emitted from the thermal station and secondary when it reacts with other elements in the atmosphere to form NO₂ and similarly NO₂ is both primary and secondary air pollutant when it reacts in the atmosphere with other elements to form nitric acid and acid rain.



1=2Km S; 2= 2Km NE; 3= 6Km NE (undetectable); 4= 2Km N; 5= 2Km SE (undetectable); 6= 6 Km NE; 7= 4Km NE; 8=2 Km NE

Figure 2: shows GPC – SO₂ µg/m³ ground level concentrations for different locations

Table 3: Nitrogen Dioxide Ground Level Concentration (µg/m³) KNPS Passive Diffusion Tubes Analysis results using U.V. Spectrophotometer

Sampling period	sample No.	sample location	Exposure time (hrs.)	Concentration in µg/m ³	ppb	World Bank guidelines	USA (NAAQO)
10/07/06	2	2Km NE	201	9.69	5.05	100 µ/m ³	100 µ/m ³
18/07/06	4	12KmNE	201	10.45	5.44	Annual	0.05ppm
	6	2KmS	201	18.23	9.50	Mean	Annual measures
18/07/06	53	2KmNE	149	12.11	6.67		
	56	12KmNE	149	20.36	10.81		
	57	2Km S	149	29.98	15.61		
	55	5Km SW	149	22.32	12.14		

N.B Results are blank subtracted

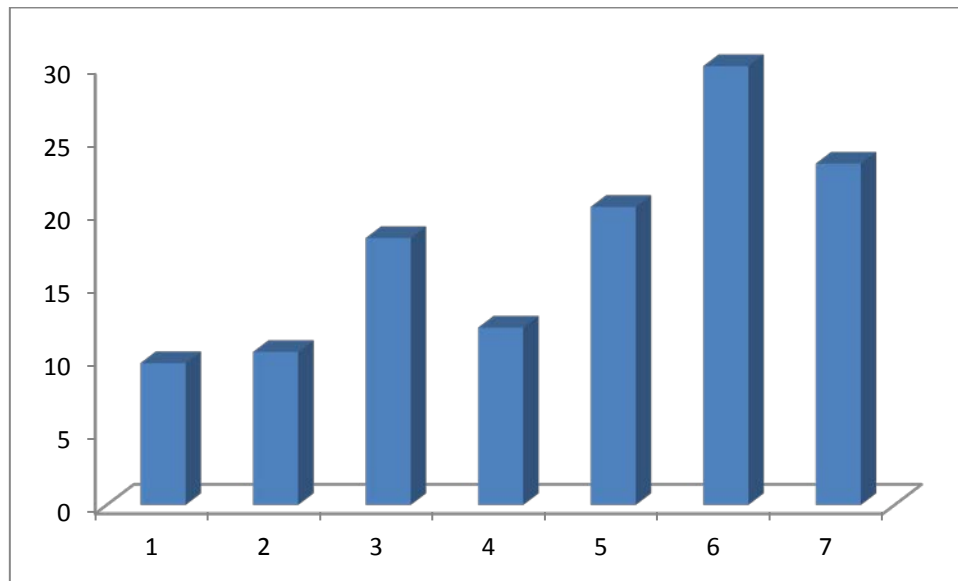
Tube Preparation: 20% TEA/Water

Limit of Detection: 0.01 microgram NO₂

Overall M.O.U. 4.39% +/-

Analysis was carried out according to what was documented in – House Laboratory Method GLM6 As reported for SO₂ emissions and concentrations of Khartoum North Power Station about half of NO₂ concentration was carried by NE winds away from KNPS 12Km NE. The concentrations observed at 12 Km NE were, 20.36µg/m³,10.81 ppb and 10.45 µg/m³, 5.44 ppb. The concentration of NO₂ at 2 Km S (Kafori

Residential Area) were very high $29.98 \mu\text{g}/\text{m}^3$, 15.61 ppb and $18.23 \mu\text{g}/\text{m}^3$, 9.50 ppb . The concentration of NO_2 emitted at 5 Km SW (El Saffia Urban Area) was $22.38 \mu\text{g}/\text{m}^3$, 12.14 ppb . The high values of NO_2 are due to combustion of KNPS, factories, garbage, burned tires and traffic.



1=2Km NE; 2= 12Km NE; 3=2Km S; 4= 2Km NE; 5=12 Km NE; 6= 2Km S; 7= 5Km SW

Figure 3: shows KNPS – $\text{NO}_2 \mu\text{g}/\text{m}^3$ ground level concentration for different locations

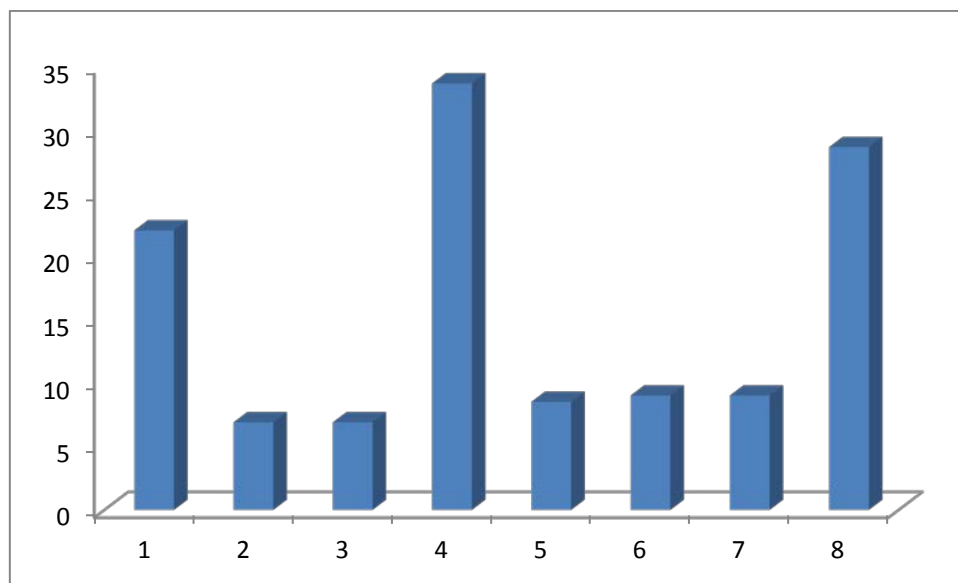
- The results of NO_2 emissions and concentrations at ground level GPC are presented in table 4 and figure 4. as seen for SO_2 emission at KNPS most of the NO_2 were carried by wind NE for a distance of 2Km NE, and 6 Km NE.

Table 4: Nitrogen Dioxide Ground Level Concentration ($\mu\text{g}/\text{m}^3$) Garri Power Complex (GPC) Passive Diffusion Tubes Analysis Results using UV Spectrophotometry (UV S003 Cecil)

Sampling period	sample No.	sample location	Exposure time (hrs.)	Concentration in $\mu\text{g}/\text{m}^3$	ppb	World Bank guidelines	USA (NAAQS)
19/07/06	36	2Km S	144	22	11.48	$100 \mu\text{g}/\text{m}^3$	$100 \mu\text{g}/\text{m}^3$
25/07/06	37	2Km NE	144	6.92	3.60	Annual mean	Annual mean
	38	6Km NE	144	6.92	3.6		
25/07/06	100	2Kms N	152	33.66	17.53		
	101	2Km SE	152	8.54	4.45		
	102	6Km NE	152	9.04	4.71		
	103	4 Km NE	152	9.04	4.71		
	104	2Km NE	152	28.63	14.91		

The highest NO_2 emission and concentration observed was $33.66 \mu\text{g}/\text{m}^3$, 17.53 ppb at 2 Km N. At 2Km S, NO_2 emission and concentration was $22.00 \mu\text{g}/\text{m}^3$, 11.48 ppb 2km S.

The author [6] stated that dry air consists 78% N and 20% O [12]. In combustion engines N and O react in presence of an active hydrocarbon internally or O and N react in presence of lightening externally. Combustion scientists classify Nitrogen oxides found in combustion gases as thermal, prompt and fuel NOs [13]. In thermal plants and traffic means (cars, buses, heavy moving machines are the main source of NO₂ air pollution. KOR is a source of NO₂ pollution during petroleum refining and the flare tower which is 100m high and 600m fro GPC. The range of NO₂ emission, concentration and pollution in KNPS and GPC 6.2µg/m³,3.6 ppb-33.66µg/m³,17.53 ppb shows comparatively high NO₂ air pollution compared with ambient air quality standards of UK, EU 40µg/m³ and within limits of USA 100µg/m³.



1= 2Km S; 2= 2Km NE; 3= 6Km NE; 4= 2Km N; 5= 2Km SE; 6= 6 Km NE; 7= 4Km NE; 8= 2 Km NE

Figure 4: shows GPC – NO₂ µg/m³ ground level concentrations for different locations.

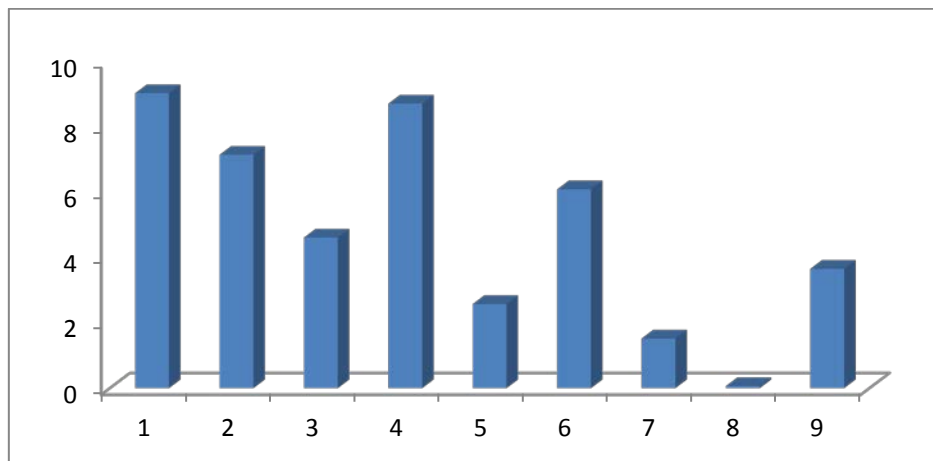
- The results of ammonia emission and concentration at ground level for GPC are presented in table 5 and figure 5. Ammonia is grouped as NH_y, some of NH₃ and NH₄. It is a reduced form of Nitrogen Oxides [14]. Author [20] cited by author [5] stated that live- stock farming and animal waste account for the biggest percentage of total ammonia emission due to decomposition of urea from large animal waste and uric acid from poultry. Author's [6] information on global ammonia emission showed that live- stock contributes 50% of all emissions, fertilizers application , oceans, vegetations and biomass burning. Author [3] reported that live- stock and poultry contribute 94% of ammonia in Romania. Reduction in live- stock numbers resulted in decrease of ammonia pollution. Author [21] cited by [5] stated that exposure to very high concentration of ammonia in the air may result in lung damage and death.

The results in table 5 and figure 5 low concentration of ammonia emitted from GPC: ranging from 0.063µg/m³, 0.088 ppb up to 9.03 µg/m³, 12.73 ppb. Ammonia gas was recorded at 9 Km SE: 4.63 µg/m³, 6.52 ppb (farming area). The rest of ammonia concentration was confined to 2Km from GPC in different directions. The highest

values were 9.03 $\mu\text{g}/\text{m}^3$ 12.73 ppb S; 7.14 $\mu\text{g}/\text{m}^3$, 10.07 ppb NE; 8.72 $\mu\text{g}/\text{m}^3$, 12.29 ppb N; 6.08 $\mu\text{g}/\text{m}^3$, 8.52 ppb W; 3.66 $\mu\text{g}/\text{m}^3$, 5.17 ppb NE and 0.063 $\mu\text{g}/\text{m}^3$, 0.088 ppb S. These values show that ammonia emitted and concentrated in all directions at 2 Km around GPC and KOR residential area. The low value of ammonia of 4.63 $\mu\text{g}/\text{m}^3$, 6.52ppb at 9 Km SE is due to lack of intensive live- stock and poultry production. Continuous monitoring of ammonia emission and concentration in residential area is important to keep it within permissible limits aloud.

Table 5: Ammonia (NH₃) Ground Level Concentration ($\mu\text{g}/\text{m}^3$) – (GPC) Passive Diffusion Tubes Analysis Results using ion Chromatography

Sampling period	Sample No.	Sample location	Exposure time (hrs.)	Concentration in $\mu\text{g}/\text{m}^3$	ppb	OSHA
19/07/06	27	2Km NE	148	9.03	12.73	Exposure unit 25 ppm
	29	2Km NE	148	7.144	10.07	
	30	9Km SE	148	4.63	6.52	
19/07/06	73	2Km N	148	8.72	12.29	Exposure limit 35ppm
	74	2Km S	148	2.58	3.64	
	75	2Km W	148	6.4	8.52	
	78	9 Km N	148	damaged		
	81	2 Km N	152	1.52	2.14	
	82	2 Km S	152	0.063	0.088	
	83	2 Km NE	152	3.66	5.17	
	84	9 Km SE	152	Grid was lost		



1= 2Km S; 2= 2Km NE; 3= 9Km SE; 4= 2Km N; 5= 2Km S; 6= 2Km W; 7=2 Km W; 8= 0.063; 9= 3.66

Figure 5: shows (GPC) – NH₃ $\mu\text{g}/\text{m}^3$ ground level concentrations for different locations

4. Conclusion

The chemical, mechanical, physical and acoustic air pollution had not been brought to the attention of the policy-makers in the Sudan. The citizens are not aware of it due to several factors. The Sudan is a vast country sparsely populated. It depends on traditional agriculture, live-stock raising and industrial activity in Khartoum State. The impact of air pollution on human, animal health and environment is not felt up to now. The recent development in oil production and refining and its effect on air pollution by SO₂, NO₂, and NH₃ has not been investigated. In developing countries USA and China had been classified as the biggest polluters. The two countries had plans and policies to reduce Carbon peaks and ambitiously working towards their goals (in Paris talk, December 2015) [15].

The results of SO₂, NO₂, and NH₃ emissions and concentrations of air in Khartoum North and Garri Thermal Plants had shown low level of SO₂ pollution specially GPC where low sulphur oil is used (0.116 up to 0.25% sulphur). This thermal generation, 30% at present can be reduced and hydro-electrical generation can be increased more than 70%. Renewable sources (solar and wind could be used in electrical generation.

Although the limit of NO₂, air pollution in KNPS and GPC are lower than UK, EU 40µg/m³, and USA 100 µg/m³, policy makers are advised to set policies of reducing the large numbers of importing second hand means of transport.

Rules and regulations should be set and imposed to reduce air pollution levels and adopt air pollution levels licensing for means of transport and heavy moving machines.

Air pollution with ammonia is associated with live-stock, poultry intensive production and industrial ammonia, fertilizer production.

The results show that ammonia emissions and concentrations in GPC are within permissible limits. Air quality and exposure to permissible limits had to be observed. The farming areas at 9 Km from the ammonia pollution source were very low (4.63 µg/m³, 6.52 ppb).

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