

Background Concentration of NO₂ Prior to Construction and Operation of a Gas-Fired Power Plant in the Niger Delta Region of Nigeria

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Abstract

Concentrations of NO₂ were monitored in the ambient air during a one-year period in an area proposed for a major upgrade of an existing gas-fired power plant and the construction and operation of a new gas-fired power plant. The new plant will be located immediately adjacent to the existing facility. The exercise was with a view to establish the status of NO₂ in this environment prior to commencement of project activities. The project area is predominantly rural and the existing power plant, the only anthropogenic source of NO₂ in the area at the moment, was operating at below optimal capacity. Seven sites were chosen to cover an area within a radius of 5 km of the power station. Another site, 13 km further downwind of the power station was also chosen. It was not possible to choose an area as further upwind as the 13 km downwind site because of the potential influence of both a petrochemical plant and a natural gas processing facility. The survey covered the two seasons prevalent in the Niger Delta region of Nigeria and the existing power station was operating at the same throughput the period of the survey. Nitrogen dioxide concentrations ranged from 8.5 µg/m³ in September to 22.4 µg/m³ in January. The annual mean values ranged from 14.5 to 15.7 µg/m³. These values were considerably below the Nigerian ambient air quality standards recommended by the Federal Ministry of Environment and the World Health Organization air quality guide values. They were however consistently higher during the dry season than during the rainy season. The concentrations were particularly low during July and September; the two months with the highest rainfall. There are on comprehensive data on the ambient concentrations of NO₂ for the two seasons in the project area. This survey is, therefore, significant because it will form the basis against which future ambient concentration changes in NO₂ will be compared.

Key words : Nitrogen dioxide, Pollutant, Power plant, Saltzman method, Air quality.

Through a government power sector reform program, a private developer has taken over the management of the development and operation of Afam power station (and most of its ancillary facilities) for a period of twenty-five years under a lease-operate-transfer agreement. Afam power station was one of the power stations of the government-owned Power Holding Company of Nigeria (PHCN). The private developer has also proposed the construction and operation of a new facility under a build-operate-transfer agreement. PHCN was the sole monopoly empowered by law to generate, transmit and distribute elec-

tric power in Nigeria. The proposed new facility will be a combined cycle gas turbine (CCGT) power plant capable of generating between 600 mega watts (MW) and 700 MW of electricity from the combustion of approximately 190 MMscf/d of nature gas. The new plant will be sited at a location adjacent to the existing power station. This existing power station has five trains, all operating as open cycle gas turbines (OCGT). This project is aimed at increasing the electric power generating capacity in Nigeria by more than 25%. The first train was installed in 1962; it had 4 turbines and was rated 56 MW. Since then, the power

Table 1. Air quality standards.

Directive 2001/80/EC Emission Limits				
Parameter	Emission limit			
Oxides of nitrogen (expressed at NO ₂ equivalent)	50 mg/Nm ³			
World Bank Emission Limits				
Parameter	Emission limit			
Oxides of nitrogen (expressed as NO ₂ equivalent)	125 mg/Nm ³			
Nigerian Ambient Air Quality Standards				
Parameter	Time of Average	Limit		
Nitrogen oxides (nitrogen dioxide)	Daily average of	0.04—0.06 ppm		
	hourly values (range)	(75—113 µg/m ³)		
EU Air Quality Standards				
Parameter	Reference period	Compliance date	Statutory ground level concentration limit values (µg/m ³)	Number of permitted exceedences
Nitrogen dioxide	Hourly	2010	200	18
	Annual (for the protection of human health)	2010	40	—
World Bank Air Quality Limits				
	Reference period	Recommended ground level concentration values		
Nitrogen dioxide	24 hour average	150 µg/m ³		
	Annual average	100 µg/m ³		
WHO Air Quality Guide Values				
	Reference period	Recommended ground level concentration guide values		
Nitrogen dioxide	1 hour average	200 µg/m ³		
	Annual average	40 µg/m ³		

station has grown into a 20-turbine facility comprising trains I-V. Train I is no longer operational. Trains

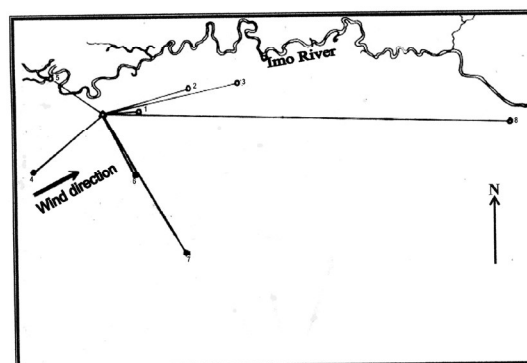


Figure 1. Sampling locations for air quality. The symbol represents the location of the power station.

II, III and IV, however, still have operational units with combined installed rating of 654 MW. However, at the time of this study, the combined output of these three trains was less than 100 MW (1). Train V, commissioned in 2001, has an installed capacity of 314 MW and consists of two Siemens V94.2 gas turbines. For the new facility, a contract has been let for the construction of train VI and it is planned to be immediately adjacent to train V. Once train VI comes on stream, existing trains I—IV of the power station shall be decommissioned and dismantled. Train VI will replace the capacity of trains I—IV. The private developer shall operate the upgraded facility for approximately 25 years after which the power station and its ancillary facilities shall be handed back to PHCN. The 900 + MW of electricity expected to be generated in this power station shall be sold to PHCN under a power purchase agreement.

In Nigeria, there is a gross absence of air quality data especially in the location of the proposed development. This is because at the time of the initial construction of the power plant in 1962, there was no legislative and regulatory framework to ensure that the construction and operation of the power station and its ancillary activities were executed without adverse effects on the natural environment and the people who inhabit it. Even during additions of subsequent trains in 1976, 1978 and 1986, efforts made to follow due process were frustrated ostensibly because they were projects of government (1). Also, attempts at building comprehensive environmental data base for the Niger Delta region for the purposes of petro-

Table 2. Sampling stations relative the power plant location.

Station 1	Ayama	4°51'10" N	7°15'56" E	1 1/4 km downwind of power plant
Station 2	Obunku	4°51'33" N	7°16'50" E	2 1/4 km "
Station 3	Umuosi	4°53'36" N	7°08'41" E	4 1/2 km "
Station 4	Well OKOL 001	4°52'35" N	7°14'12" E	3 km upwind of power plant
Station 5	Well 6 location	4°51'35" N	7°14'29" E	2 km crosswind of power plant
Station 6	Egberu/Okoloma road	4°50'31" N	7°15'32" E	2 km "
Station 7	Egberu	4°48'54" N	7°16'45" E	5 1/4 km "
Station 8	Umu Abayi	4°49'56" N	7°14'09" E	13 km downwind of power plant

leum pollution monitoring curiously did not include air quality studies (2, 3). In compliance with the legislative and regulatory requirements of the Federal Ministry of Environment for major projects, air quality studies to establish the current state of the receiving environment prior to the commencement of project activities were carried out as part of an environmental impact assessment study for this power project. The air pollutants which are listed in the Guidelines and Standards for Environmental Pollution Control in Nigeria are particulates, sulfur oxides (as sulfur dioxide), non-methane hydrocarbons, carbon monoxide and nitrogen oxides (as nitrogen dioxide) (4).

During construction, machinery and vehicles will emit nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO₂), sulfur dioxide (SO₂) and particulate matter. Construction activities can also give rise to emissions of particulates. During operation, the combustion of natural gas will give rise to emissions of nitrogen oxides, carbon monoxide, carbon dioxide, sulfur dioxide and particulate matter. Combusting in gas turbines is conducted at high excess air rates, typically 200–300% excess air. There are, therefore, low levels of carbon monoxide, un-burnt carbon (i.e. particulate matter) or un-burnt volatile organic compounds (VOC) present in the products of combustion when burning gaseous fuels (5–7). Carbon dioxide is a greenhouse gas, with increased levels in the atmosphere being linked to global warming. Under the proposed base-load operating scenarios, the new plant would emit approximately 3 million t/annum. The new facilities are expected to produce less CO₂ per MW generated compared with the majority of installed capacity (8). The quantity of sulfur dioxide emitted from a combustion process depends on the sulfur content of the fuel. Typically, levels of sulfur in natural gas are negligible. Actually, initial analysis of gas to be used in the proposed project

supports this assumption (9). This natural gas is not odorised with methyl mercaptans, which can be a source of sulfur in odorised natural gas. Emissions of sulfur dioxide from the proposed power plant are, therefore, unlikely to be significant.

Several activities associated with the construction works have the potential of emitting dust should preventive measures not be taken. For example, dust could arise from: earth-moving operations for back-filling and foundations; removal of spoil, site stripping and blow-off; concreting operations, site reinstatement and road construction and during wind blow over bare dry construction areas. The smallest dust particles, i.e. those with a diameter of less than 10 microns (10), however, are the most likely to be deposited in the lung and therefore have the greatest potential for causing health impacts. Large diameter dust particle (50–200 microns) are expected to be emitted during construction. This will tend to resettle on the ground within 100 to 500 m of the site. Approximately 70% of the dust will generally settle out

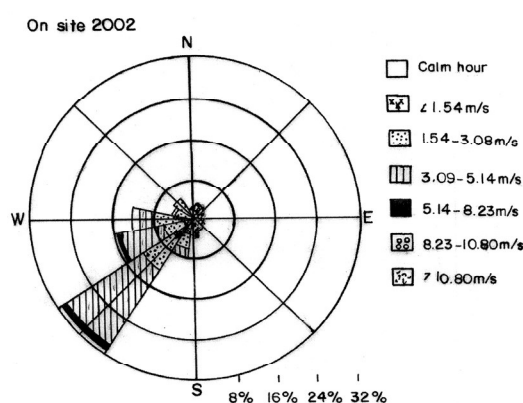
**Figure 2.** Wind rose of Bonny Island (adapted from FMENV 2005).

Table 3. Dispersion modelling data (existing plant).

Parameter		Afam II	Afam III	Afam IV	Afam V	Afam V
Fuel burn	Kg/s	2.57	2.57	6.26	8.44	8.44
NO _x emission level	mg/Nm ³	450	450	450	70	450
NO _x flow rate	g/s	49.9	49.9	121	25.5	164
Flue gas temperature	K	736	793	753	836	836
Stack diameter	m	3.30	3.30	7.00	7.10	7.10
Flue gas velocity	m/s	37.0	40.0	21.0	30.0	30.0
Normalized flue gas flow rate (dry, 15% O ₂ , 0 C)	Nm ³ /s	111	111	269	364	364
Actual flue gas rate	m ³ /s	318	343	792	1190	1190
Stack height	m	16.0	16.5	25.0	20.0	20.0

of the atmosphere within 200 m of the source and less than 10% could be expected to remain at a distance of 400 m (10, 11). The construction process is planned to be of relatively short duration. They are, therefore not anticipated to be any long-term effects attributable to dust emissions from the project.

Nitrogen oxides are emitted into the atmosphere by human activities, primarily as a result of the combustion of fuels. Approximately 80% of these emission arises from the oxidation of nitrogen in the fuel. The remaining 20% arises from the oxidation of atmospheric nitrogen in the heat of combustion (12, 13). Both nitric oxide (NO) and nitrogen dioxide (NO₂) are formed. Although NO predominates, upon release into the atmosphere it is fairly reactive and is readily oxidized to NO₂ through several chemical reactions which depend on the concentrations of NO. The reaction is reversible in sunlight; hence, the balance between NO and NO₂ may vary with time of day, the proximity of sources and atmospheric factors. For convenience, researchers refer to NO and NO₂ collectively as oxides of nitrogen (NO_x). In general, however, concentrations of NO are small compared to NO₂ in unpolluted rural areas but could be much higher and often may exceed those of NO₂ in polluted air (13). Nitrogen dioxide is of potential concern to human health and local ecology and in relation to its potential contribution to greenhouse gas levels (11). Oxides of nitrogen are one of the components of photochemical smog and high levels of NO₂ are thought to increase the risk of respiratory diseases and con-

tribute to heart, lung, liver and kidney damage and eye irritation (14, 15). Concentrations of nitrogen dioxide (NO₂) only were monitored in this work. This is because nitrogen dioxide is the only product of gas-fired combined cycle gas turbine operation likely to have a potential significant environmental impact (5–7). The objective was to establish the concentration of NO₂ in the ambient air of the project area prior to commencement of activities. This background data shall be used to monitor future changes in ambient air concentrations of NO₂ when operations commence.

(The authors wish to acknowledge the assistance of Mr E. E. Okon in collecting the samples. The contributions of Mr Chisom Dike and the other members of the project area communities who participated in the sample collection exercise are sincerely appreciated. Thanks are also due to the managements of the Institute of Pollution Studies, Rivers State University of Science and Technology and of Ideyi Consult Limited for the use of their analytical facilities).

Location of the Proposed Project

The proposed development is located approximately 30 km northeast of Port Harcourt in the Niger Delta region of Nigeria. It lies roughly between latitudes 4°45'00'' N–4°55' N and between longitudes 7°10'00'' E–7°20'00'' E. The power station is bound in the north by Imo River, east by a village called Ayama, south by a village called Egberu and west by the local government headquarters in Okoloma, the community where the power plant is located. The project's area of influence covered an area of approximately 157.20 km² and is well fed Imo River with the riparian swamp forest, which is made up of rainforests and secondary forests along its course. The swamp forests and farmlands form the major topographical land cover which consists of low-lying, relatively flat terrain with dendritic channels through which the area is drained (16). The swamp forests around the fringes of the Imo River experience seasonal flooding. Agriculture is the major activity in the project area (9).

Relevant Regulatory Guidelines

The World Health Organization (WHO) has set ambient air quality guidelines for the pollutants of interest. The guidelines of the European Union and

Table 4. On-site mean wind speed and predominant direction. *1 knot=0.52m/sec.

	Sampling Locations Longitude Latitude		Mean wind speed (knots*)		Predominant Wind Direction	
			at Location		Wind Direction	
			Dry Season	Rainy Season	Dry Season	Rainy Season
1	7°14'12''E	4°52'35''N	4.23	3.88	N	SW
2	7°14'29''E	4°51'35''N	4.02	4.38	NW	SW
3	7°16'45''E	4°48'54''N	3.18	3.89	NW	SW/W
4	7°15'56''E	4°51'10''N	4.37	3.84	N	SW
5	7°16'50''E	4°51'33''N	3.82	2.93	N/NW	Calm
6	7°08'41''E	4°53'36''N	3.63	3.43	SW	SW
7	7°15'31''E	4°50'31''N	3.92	4.18	SW	SW
8	7°14'09''E	4°49'56''N	4.01	4.02	W	Calm

World Bank are also referred to. The air emissions and air quality guidelines that may be applied to this project are presented below.

Emission Limits. There are currently no specific regulatory limits or guidelines for the atmospheric emission of air pollutants from gas turbine plant in Nigeria. General limits are, however, given in some case (4). Those of potential interest to this power project are : Carbon dioxide (CO₂) from stationary sources=10% by volume; oxides of nitrogen (NO_x) from stationary sources=359—1000 mg/m³.

For train VI, CO₂ emissions are expected to be approximately 3% by volume and NO₂ emissions are expected to be lower than 50 mg/Nm³ (Nm³ is a cubic meter of a dry sample of gas normalized to 15% O₂ at 273 K and 101.3 kPa) (8). In the European Union it is the Large Combustion Plant Directive (2001/80/EC), which is used as a source for emission limits for power plant with an output of greater than 50 MW. The Directive gives the emission limits presented in Table 1 for gas turbines, firing natural gas, at reference conditions 15% oxygen, dry (273 K, 101.3 kPa) for gas turbine loads above 70%. The World Bank Group Pollution Prevention and Abatement Handbook gives the following emission limits for gas turbines at reference conditions 15% oxygen, dry (273 K, 101.3 kPa) (Table 1).

Ambient Air Quality Guidelines. The Federal Ministry of Environment (formerly Federal Environmental Protection Agency (FEPA) in the 1991 Guidelines and Standards for Environmental Pollution Control in Nigeria provides general air quality standards (Table 1). The European Community has also set am-

bient air quality guidelines for NO₂. A summary of Directive 99/30/EC is given in Table 1. The World Bank Pollution Prevention and Abatement Handbook provide ambient air quality guidelines, which are shown in Table 1 below : Only the Nigerian standards will apply to ground level concentrations of NO₂ attributable to the power plant; however, air quality guidelines from the World Health Organization (WHO) may be used for reference and are given in Table 1.

The limit values are similar or more lenient than those of the European Union for the same averaging periods. The WHO also includes additional or differing averaging periods to those of the European Union. The WHO does not recommend guideline levels for ambient particulate matter, in this from construction, as the organization believes that the available epidemiological information does not allow a judgment to be made of concentrations below which no effects would be expected (17).

Methods

Sampling Scheme

Two main types of schemes for making discontinuous air pollution measurements are recognized (18, 19). In the first, measurements are made simultaneously at a number of fixed measuring points and these measurements of air quality are related to meteorological measurements made at the same time. For this study this scheme was ruled out because facilities for such an exercise were not available. In the second, measurements are made with a group of instruments which are moved from one fixed measuring point to another in a predetermined manner. These measurements are then related to meteorological data made at the same time or obtained from a synoptic meteorological station.

For this study, this second scheme was adopted because of the nature of our group of instruments. An advantage of this scheme is that a large area was covered with a minimum number of instruments. The data obtained fulfil the main objectives of characterizing air quality and checking adherence to air quality standards. Although manpower demands are higher than in the first scheme, this opportunity was used to involve enlightened members of the local communities in the sample collection exercises so as to earn their trust and build confidence in the environmental

assessment process.

Sampling Locations

The selection of sites was determined by the prevailing wind direction and the need to make measurements near areas susceptible to pollution such as residential areas. A total of eight sampling station georeferenced using Magellan Meridian Platinum GPS Receiver with built-in map and 3-Axis electronic compass and barometer were used for this exercise. These sampling stations are upwind, downwind and crosswind of the power plant and are shown in Table 2.

Stations 4 and 8 were intended to be controls; station 4 is upwind of the power station while station 8 is remote from the power station location. Station 4 is an abandoned oil well location. The choice of a station further west or southwest of station 4 will bring that station under the possible influence of both a natural gas processing plant and a petrochemical complex. These facilities are less than 10 km south southwest of station 4. It was not possible to go directly downwind because of the claim by the natives that the forests beyond the river are century's old forests in which strangers are not permitted to enter.

Distance from the Source in Different Wind Directions

The flue gas exits chimney stacks of heights greater than 10 m from the ground. Thus, the products of combustion will not reach the ground for some distance downwind of the stack. Naturally, the concentration of NO_2 will rise fairly rapidly to a maximum value after which it will decrease slowly with distance downwind of the source (20, 21). Although taking measurements close to the source could not only help detect leakages but also serves as a reference, it was observed that a huge gully exists between the battery limits of the piece of land chosen for the proposed power plant and a local community, a distance of less than one kilometer. It was, therefore not possible to sample air at locations too near the power plant. Using information from the existing plant (Table 3) and SCREEN3, the USEPA air dispersion screening model (22), the maximum concentration was approximated to lie between 20 to 30 m effective stack height from the base of the stack and the maximum concen-

tration estimated as $20 \mu\text{g}/\text{m}^3$. The other locations were selected at approximately 1 km intervals from this maximum up to a distance of 5 km. This is because in general the highest concentrations of pollution will be measured within a radius of 5 km of the facility emitting the pollutant (18). These sampling stations are indicated in Figure 1.

Sample Collection

The WHO has selected methods of analyzing air pollutants. These methods are based on those adopted by the United States Environmental Protection Agency (EPA), EC (23). The Federal Ministry of Environment in Nigeria has adopted these methods for the purpose of surveillance and monitoring air pollutants. The adopted Saltzman method for NO_2 was used in this study (4, 13, 23–26).

At each sampling station, one-hourly sample was collected to enable analysis for nitrogen oxides as nitrogen dioxide. A replicate sample was also collected. The group of equipment for air quality sampling (which consisted of two 60 ml midget fitted bubblers each containing a solution of the Saltzman reagent, a rotameter, a suction pump, a timing device, a power generator) was moved from sampling station to sampling station after sampling was concluded at a particular sampling location. In this study, the Saltzman reagent was obtained by mixing one part distilled water : one part sulphanilamide reagent (2 g sulphanilamide plus 5 ml concentrated phosphoric acid diluted to 100 ml with distilled water) : one-tenth part N-1-naphthylethylene-diamine-dihydrochloride reagent (13). For practical and security reasons, mea-

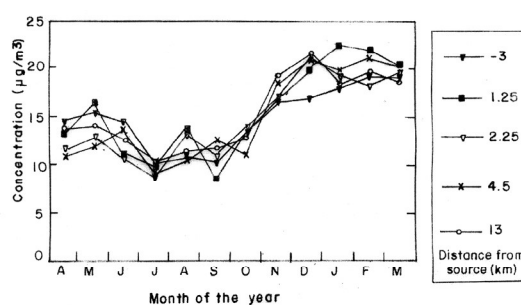


Figure 3. Observed concentration of NO_2 as a function of month of the year with distance from the source as parameter.

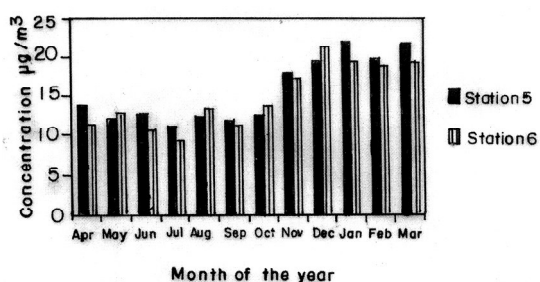


Figure 4. Concentration of NO₂ in the crosswind direction of the power plant.

surements were not made at night. Some weather conditions were therefore not covered. This was considered as a limitation.

The Saltzman method is based on the specific reaction of nitrite ion with diazotizing-coupling reagents to form a deeply colored azo dye which is measured spectrophotometrically at 550 nm (23–25). A Bausch and Lomb Spectronic Instrument, Model 21D spectrophotometer previously calibrated with known concentrations of NO₂ was used. The NO₂ in the ambient air is drawn by bubbler devices and converted to nitrite ion through contact with an absorbing solution containing the diazotizing-coupling reagents (absorbing solution). The method is standardized by using sodium nitrite standards. The concentration of NO₂ in the sample is read from a calibration curve and related to the sampling time and the volume of air sampled in cubic meters (m³). This method is intended for the manual determination of NO₂ in the atmosphere in the concentration range from 0.005 to about 5 ppm (0.01 to 9.400 µg/m³) at flow rate of up to 0.6 liter/min of sampled air. The composition of the Saltzman reagent is given in several documents (15, 23, 25).

At the start of the survey, it was intended that sampling would be from 0630–0730 h (station 1); 0800–0900 h (station 2); 0930–1030 h (station 3); 1100–1200 h (station 4); 1230–1330 h (station 5); 1400–1500 h (station 6); 1530–1630 h (station 7); and 1700–1800 h (station 8) in that order so that the day-time hours of each sampling day were devoted to the eight sampling stations. The strategy was to cover all the sampling locations within these hours and repeat the exercise the same day of the week,

once a week from April 2004 to March 2005 to cover the two seasons prevalent in the Niger Delta region of Nigeria (i.e. rainy season—April to October; dry season—November to March). The principle is that a sampling location will be visited at a particular time each day of sampling (27). Although the full day-time hours were devoted to the eight sampling stations in the order indicated, it was not always possible to meet this timing arrangement because of traffic hold-ups and interruptions from communities.

For more than two years before the field study, trains II-IV power plants were operated at less than 15% of installed capacity while train V was operated at approximately 35% capacity. A high-ranking company official confirmed that these plants were operational throughout the period of the field survey at the stated throughput. During the sampling, care was taken to avoid undue interference from any external gaseous emission source while sampling. For example, the power generating set was located downwind of the sampling point at a distance of approximately 50 meters. When sampling was done in communities as in sampling location 1, 2, 3, 7 and 8, sampling was done at the outskirts of these communities, in the primary school field, free from domestic cooking smoke. Wind speed and direction were also measured using DEM 6 Anemometer, supported by KESTREL 3000 Weather Meter for wind speed.

This information is in addition to the meteorological data which is monitored in Bonny Island, Nigeria, a distance of approximately 40 km south of the project area (9).

Results and Discussion

Wind Speed and Direction

The discrete on-site wind direction and speed information is shown in Table 4. The winds were less than 5 knots and predominantly south-westerly in direction, sometimes from the westerly direction. North-westerly winds carrying desert sand (the harmattan) occurred during the dry season, especially from December to January. The wind condition from Bonny Island is shown as a wind rose in Figure 2. The on-site wind direction and speed information have the same general pattern as the wind rose from Bonny Island suggesting that the study area is influenced by similar weather patterns (9).

Table 5. Mean and standard deviation* of monthly NO₂ concentration (µg/m³). *SD=Standard deviation.

Sampling station	Mean monthly day-time NO ₂ concentration (µg/m ³)												Annual mean
	A	M	J	J	A	S	O	N	D	J	F	M	
1	13.2	16.1	10.5	9.7	13.1	8.5	13.2	16.7	19.8	22.4	21.8	20.3	15.4
SD	(1.3)	(2.1)	(0.8)	(0.6)	(2.8)	(1.1)	(1.2)	(1.8)	(2.3)	(2.7)	(0.9)	(1.6)	(1.7)
2	15.2	14.3	13.1	9.4	12.5	9.2	11.3	14.1	20.3	19.8	20.9	18.3	14.5
SD	(0.9)	(1.9)	(0.8)	(1.6)	(3.2)	(0.7)	(2.1)	(0.6)	(1.4)	(2.4)	(1.7)	(2.1)	(0.8)
3	12.3	13.1	10.3	10.5	12.1	11.2	12.1	17.5	21.4	18.3	19.4	19.6	14.8
SD	(1.4)	(2.2)	(0.7)	(1.6)	(1.2)	(1.3)	(0.8)	(2.4)	(1.4)	(2.1)	(1.5)	(1.6)	(1.2)
4	14.2	15.4	14.3	10.2	11.3	10.4	13.8	17.1	16.7	18.3	19.4	19.6	14.8
SD	(1.5)	(1.7)	(2.4)	(0.8)	(1.3)	(0.9)	(1.6)	(1.3)	(1.3)	(0.7)	(2.1)	(1.1)	(2.2)
5	13.8	12.1	12.8	11.2	12.4	11.9	12.7	18.1	19.7	21.8	19.8	21.9	15.7
SD	(1.4)	(0.8)	(1.1)	(0.9)	(1.2)	(2.3)	(1.4)	(0.8)	(0.5)	(1.8)	(2.3)	(1.4)	(1.3)
6	11.3	12.8	10.5	9.2	13.3	11.4	13.7	17.2	21.3	19.4	18.7	19.3	14.8
SD	(0.8)	(1.2)	(0.6)	(1.1)	(0.9)	(1.3)	(0.8)	(1.6)	(1.3)	(0.9)	(1.2)	(1.4)	(1.1)
7	10.7	11.9	13.3	9.4	10.5	12.6	11.1	18.2	20.4	19.7	21.1	20.3	14.9
SD	(1.6)	(1.2)	(1.1)	(1.3)	(0.9)	(1.4)	(0.8)	(1.2)	(2.2)	(1.8)	(1.4)	(1.6)	(1.8)
8	13.3	13.8	12.6	10.3	11.1	11.9	12.8	19.2	21.3	18.4	19.5	18.7	15.2
SD	(1.4)	(1.2)	(0.9)	(1.4)	(1.6)	(0.9)	(1.8)	(2.1)	(1.4)	(1.1)	(1.5)	(0.8)	(1.6)

Air Quality

Table 5 shows that mean and standard deviation of the monthly nitrogen dioxide concentration observed at the sampling stations in the study area during the study period. The values ranged from 8.5 µg/m³ in September to 22.4 µg/m³ in January, all in station 1. The annual mean ranged from 14.5 µg/m³ in station 2 to 15.7 µg/m³ in station 5.

The mean concentration during the dry season was consistently higher than what was observed during the rainy season for all the sampling locations. Line graphs (concentration against month of the year with distance in the downwind direction as parameter) presented as Figure 3 showed that a maximum concentration occurred in January and a minimum concentration occurred during September at a distance of 1.25 km from the source. The lower values in the rainy season were attributed to the heavy rainfall normally experienced in the project area during rainy seasons especially during July and September, the peak rain months (28). Pollutants are removed from the atmosphere through dry deposition to the ground, chemical reactions but during rainfall, pollutants are also washed out by rain onto rivers, vegetation and soil (21, 29, 30). Stations 1, 2, 6 and 7 had concentrations less than 10 µg/m³ in July; concentration less than 10 µg/m³ was observed for stations 1 and 2 in September. All the other sampling stations had con-

centrations greater than 10 µg/m³ for the two seasons.

The crosswind distribution (presented in Fig. 4) indicated that with exception of January and March, there was no major difference between the concentrations of NO₂ observed for sampling stations 5.2 km NW of the power station : 21.8 µg/m³–January; 21.9 µg/m³–March and sampling stations 6.25 km SE of the power station : 19.3 µg/m³–January; 19.3 µg/m³–March. Stations 5 and 6 are the crosswind locations. The concentration of NO₂ was slightly higher at station 5 than at station 6 for these two months. For the upwind direction (sampling station 4, 3 km SW of the power station) and downwind direction (sampling station 3, 4.5 km ENE of the power station), a concentration of 21.4 µg/m³ was observed for station 3 while a concentration of 16.7 µg/m³ was observed for sampling station 4 in December as shown in Figure 5. From April through June, higher concentrations of NO₂ were observed for the upwind station 4 than downwind station 3. It may be noted that these were the months which preceded a planned turn-around-maintenance program for a petrochemical plant located upwind of station 4. It is possible that this station may have come under the influence of the petrochemical plant. The higher concentration of NO₂ for the upwind station 4 in October is surprising as there is no obvious explanation for this observation. For the other months of the year, there was no significant

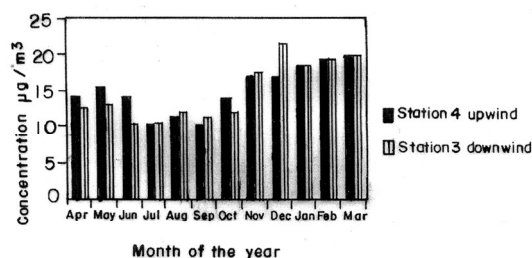


Figure 5. Concentration of NO₂ in upwind and downwind of the power plant.

difference between the concentration of NO₂ observed for sampling station 3 and 4.

As can be observed in Figure 3, the spatial variation does not obey Gaussian distribution: It does not exhibit a maximum concentration in the sense of a Gaussian plot. A comparison of the downwind and the upwind data has shown that there is no significant difference in the concentration of NO₂ between these directions.

Although this pollutant is present in the environment of the project area, its concentration (range 8.5 to 22.4 µg/m³), is below the Nigerian ambient air quality standard recommended by the Federal Ministry of Environment and the WHO air quality guide values for one hour averaging time. A companion health risk study indicated that there are no unusual health problems normally attributed to increased levels of NO₂ in the air (such as respiratory tract irritation and diseases particularly for children under five years old and the elderly) in the project area (31). The rainy season results compare favorably with those obtained in 2001 for the rainy season in a similar rural environment with a crude petroleum processing station (32).

The power plant facilities (existing trains II—V open cycle gas turbines) are the principal sources of NO_x in the area. Traffic along the local road system is relatively light especially in the vicinity of the power plant (9). A ground-truthing survey carried out by the local government authority indicated that this traffic situation has not resulted in poor air quality especially at distances of more than 100 m either side of the road (33). Other than these, the area is predominantly rural and there are at the moment, no major anthropogenic sources of air pollutants within a ra-

dius of 5 km of the power plant although a gas supply project to feed the power plant with processed gas is planned to be sited at a location approximately 2.5 km south east of the power plant.

Power generation at this station will be a commercial venture once train VI comes on stream as opposed to the previous public service under the management of former government-owned PHCN. It is, therefore, expected that the power station will operate at its optimal throughput. Emission levels are likely to increase in this circumstance although the design of train VI included the use of dry low NO_x (DNL) burners to control NO_x emissions to 50 mg/Nm³ at greater than 70% load during normal operations. It was proposed that emissions from the gas turbines of train VI should be discharged via four single-flue stacks and that these should include a continuous emissions monitoring system (CEMS) for the measurement of emissions of NO_x and other products of combustion.

For the post-commissioning ambient air concentrations of NO₂, it was also proposed that a long-term monitoring program which will utilize diffusion tubes, that give information no long-term (i.e. monthly and annual) levels of pollutants as opposed to the short-term (weekly) exercise carried out in this study be instigated. However, given the antecedents of private companies in the Niger Delta region of Nigeria, it is doubtful that this will be done. Short term exercises which are in line with the recommendations of the Nigerian national regulatory authorities, may still have to be undertaken in which case, the data reported here, which has been approved by the Federal Ministry of Environment and is now a public document will form the basis for comparisons with post-commissioning ambient levels of NO₂.

Conclusion

Ambient concentrations of NO₂ were monitored during a one-year survey in an area proposed for a major upgrade of an existing power station and the construction and operation of a new power plant. The new power plant will be located immediately adjacent to the existing facility. The survey was with a view to establish the status of this pollutant in the project area environment prior to commencement of project activities.

The area is predominantly rural and the existing power plant was operating at below optimal capacity. Traffic along the existing rural road is light and has not given rise to poor air quality in the area especially at distances of approximately 100 m either side of this road. No other anthropogenic source of NO₂ currently exists within a radius of 5 km of the power plant other than these.

Seven sites were chosen to cover an area within a radius of 5 km of the power station. Another site, 13 km further downwind of the power station was also chosen. It was not possible to choose an area as further upwind as this because of the potential influence of both a petrochemical plant and a natural gas processing facility. The survey was conducted to cover both the dry and the rainy seasons.

Nitrogen dioxide concentrations ranged from 8.5 µg/m³ in September to 22.4 µg/m³ in January. The annual mean ranged from 14.5 to 15.7 µg/m³. These values were considerably below the Nigerian ambient air quality standards recommended by the Federal Ministry of Environment and the WHO air quality guide values. They were, however, consistently higher during the dry season than during the rainy season. This is probably related to the high rainfall experienced in the project area during the rainy season. The existing power station was confirmed to be operating at the same throughput throughout the period of the study.

There are no comprehensive data on the ambient concentrations of NO₂ for the two seasons in the project area. This survey is therefore, significant because it will form the basis against which future ambient concentration changes in NO₂ will be compared.

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