Challenge of Associated Gas Flaring and Emissions Propagation in Nigeria

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Abstract: Operations at gas plants and flow stations in Nigeria involve flaring of excess gas on twenty-four hourly basis. Combustion of associated gas contributes to the atmospheric content of carbon, nitrogen, sulphur and total hydrocarbon with its resultant effect that cause damage to the environment due to acid rain formation, global warming and ozone depletion. This study evaluates the challenges of gas flaring, spatial propagation of emissions and atmospheric conditions that affect their spread using the Idu Obosi in the Niger Delta of Nigeria as a case. The AirWare Model was used in the process of determining the distribution. The results showed that at higher wind speeds (5-8m/s), emission concentrations increases at closer distances (300m-1km) and decreases at increased distances. While at lower wind speeds (1-3m/s), high concentrations are experienced from 0-8km. Emission concentrations were more prevalent at closer range under the very unstable atmospheric condition, while under the stable and neutral conditions, concentrations are at farther distances. The trajectory of the study settlement relative to the flare shows that the habited area is well within the distance range (8km) of the modeling results. It is clearly shown from the study that meteorological factors such as atmospheric stability, wind speed and direction play an important role in predicting the behavior of pollutant plumes. The dominant wind direction was south-westerly meaning that pollutants will be transported to the northern and north-eastern direction of the study area. Oil companies should endeavor to reduce gas flaring by capturing the extra gas during oil production and channeling it to useful purposes or re-injection.

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Key Words: gas flaring, emission propagation, Niger Delta.

1. Introduction

Nigeria's petroleum endowment has been exploited for more than 50 years, but while oil companies gained from the resource, local communities in the oil rich but conflict-ridden areas live with the daily pollution caused by non-stop gas flaring. It has been reported that Nigeria has one of the world's highest level of gas flaring and flares about 16 per cent of the world's total associated gas (World Bank, 2002). In Western Europe, 99 per cent of associated gas is used or re-injected into the ground. Despite regulations introduced since 1969 to outlaw the practice in Nigeria, most associated gas is flared, causing environmental pollution. Gas flaring has been reported by many researchers to be a major cause of low environmental productivity in the Niger Delta, thereby impoverishing the inhabitants (Alakpadia, 2000; Daudu, 2001; Aregbeyen and Adeoye, 2001; Udoinyang, 2005; Akpabio, 2006; Ologunorisa, 2001). Studies carried out by Odjugo and Osemwenkhae, 2009, have shown that higher temperatures and soil temperature (at 5-10 cm depths) increases as one moves closer to flare site. Comparison with control sites, which is the ecological climatic condition of the study area, shows that flaring actually modify soil, water and air micro climate. The higher temperature generated by the flare must have increased the evapo-transpiration rate in sites closer to the flare, hence decrease in the soil moisture and relative humidity. Temperature was found to have increased by 11.6^{O}C at 500m from the flare site, 9.2^{O}C at 1km and decreased to 4.3^{O}C at 2km. Also studies carried out by Ede (1995) in Agbada, Bonny, Bomu, Obagi and Tebidaba areas of Niger Delta have shown that the concentration of air borne pollutants were maximum at night and minimum during the day, and analysis of rainwater samples collected at the Bonny site by the same author showed significant concentrations of sulphates, nitrates, total dissolved solids and total suspended solids. Gas flaring is found to have significantly affected the health of the inhabitants of Otujeremu, Igbide, Olomoro, Ubeji, causing ailments that affect the respiratory, eye, skin and intestines of people impacted (Efekodo, 2001; Odjugo, 2004; Otuaga, 2004).

Gas flaring is a widely used practice for the disposal of natural gas in petroleum producing areas where there is no infrastructure to make use of the gas. It is recognized as a waste of resources and an added source of carbon emissions load to the atmosphere. Despite this recognition, there is substantial uncertainty regarding the magnitude of gas flaring. Current estimates of gas flaring volumes rely on voluntary reporting made by corporations and individual countries. There is very little independent data on gas flaring volumes and it is known that some of the reported volumes are low (NGDC, 2011). In 2004, Nigeria's volume of gas flared was equivalent to one-sixth of total gas flared in the world. Globally, the volume of gas flared between 1996-2006 (during which time awareness of the detrimental impact of flare emissions on the global climate grew) remained relatively constant, ranging between 150-170 billion cubic meters (BCM). Nigeria's share of the total volume is approximately 24.1 BCM of gas. By comparison, the U.S. flared 2.8 BCM during the same time period.

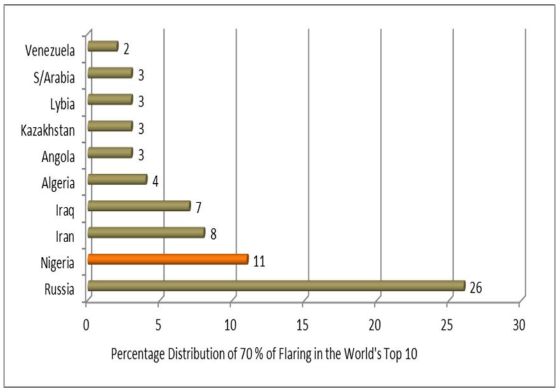

Figure 1: Top Flaring Nations (Data: Wikipedia, 2011)

Nigeria is the second biggest offending country, after Russia, in terms of the total volume of gas flared. Ironically Russia did announce it will stop the practice of gas flaring back in 2007. This step was, at least in part, a response to reports by National Oceanic and Atmospheric Administration (NOAA) that concluded Russia's previous numbers may have been underestimated. The report, which used night time light pollution satellite imagery to estimate flaring, put the estimate for Russia at 50 billion cubic meters while the official numbers are 15 or 20 BCM (Wikipedia, 2011).

The first order to reduce gas flaring in Nigeria was contained in the Petroleum Act 1969 where the operators were directed that:

"not later than five years after the commencement of production ... submit to the Minister, any feasibility study, program or proposal ... for the utilization of any natural gas, whether Associated with oil or not, which has been discovered in the relevant area."

This order was ignored. Through the Associated Gas Re-Injection Act No. 99 of 1979, the Nigerian government required oil corporations operating in Nigeria to guarantee zero flares by January 1, 1984. Oil companies nonetheless have continued to flare gas, merely paying nominal fines for breaking this law. The Act allowed some conditions for specific exemptions or the payment of a fee of US $0.003 (0.3 cents) per million cubic feet, which increased in 1988 to US $0.07 per million cubic feet, and in January 2008 to US $3.50 for every 1000 standard cubic feet of gas flared. This is still considered meager and not a deterrent for companies, which find it easier to just pay the fine. The objectives of this study are:

a) To determine the spatial profile of flare emissions and their concentrations at various receptors (distances) using the Air Quality Assessment and Management Model (AirWare).
b) To analyze the various atmospheric conditions that could enhance or worsen the air quality within the flare impact area.
c) To assess the problem of gas flaring in Nigeria and its implications.

2. Materials and Method

AirWare includes basic Gaussian model used in determining the average concentration of emissions. The accompanying 2D graphical interface generated was developed between 2005 and 2010. This model which was designed to support the European Environmental Directives (EED) also accommodates other broad range of applications and can be configured for use in specific national regulations. AirWare not only has a fully interactive, graphical and symbolic user interface, but incorporates a rule based expert system that can guide and control user requests and assures the completeness, consistency, and plausibility of data and scenarios assumptions. The main function groups that the system supports are:

- Data management and time series analysis (emission inventories, monitoring including real-time data acquisition).
- Planning, design impact assessment, optimization (emission control).
- Scenario analysis, forecasting (regular or event based).
- Communication: reporting and public information.

These groups are supported by a corresponding set of main functions and numerous auxiliary generic tools such as fully integrated GIS and the embedded expert system, as well as data import and export facilities. Basic models in AirWare also include a set of fast and efficient screening/regulative level models designed for fully interactive use, including ISC3/AERMOD (short term, 24hours, and seasonal long term), and the software can only be carried and operated on internet platforms.

2.1 Model Basic Equations:

The notation used following X in parenthesis is to give the three co-ordinates of the receptor location according to a co-ordinate scheme. Following a semi-colon, the effective height of emission of the source is given. The equation is given as four separate factors, which are multiplied by each other. These four factors represent the dependency upon emissions, or the source factor, and what occurs in the three dimensions parallel to the three coordinate axes.

$$X = (x, y, z; He) =$$

Emission factor = Q

Downwind factor = $1/U$

Crosswind factor =

$$\frac{1}{(2\pi)^{1/2}\sigma_y} \exp\left[\frac{y^2}{2\sigma^2_y}\right]$$

Vertical factor =

$$\frac{1}{(2\pi)^{1/2}\sigma_z}\left[\exp\left[\frac{-(\mathrm{He}-\mathrm{Z})^2}{2\sigma^2_z}\right]+\exp\left[\frac{-(\mathrm{He}+\mathrm{Z})^2}{2\sigma^2_z}\right]\right]$$

The notations used are as in Oke (1987):

- X → Air pollution concentration in mass per volume usually gm^{-3}
- Q → Pollutant emission rate in mass per time usually gs^{-1}
- U → Wind speed at the point of release, ms^{-1}
- σ_y → the standard deviation of concentration distribution in the crosswind direction, m at the downwind distance x
- σ_z → the standard deviation of the concentration distribution in the crosswind direction, m at the distance x
- π → the mathematical constant Pi equal to 3.1415926
- He → the effective height of the centre-line of the pollutant plume
- Z → Receptor distance above ground (m).

The concentrations at the receptor are directly proportional to the emissions. Parallel to the X axis, the concentrations are inversely proportional to wind speed. Parallel to the Y axis, that is, crosswind, the concentrations are inversely proportional to the crosswind spreading, σ_y, of the plume; the greater the downwind distance from the source, the greater the horizontal spreading, σ_y, the lower the concentration. The exponential involving the ratio of Y to σ_y just corrects for how far off the centre of the distribution the receptor is in terms of standard deviations. The receptor is y from the centre. Since the crosswind distribution centre is at y = 0, i.e. directly above the x axis. Parallel to the Z axis, i.e. vertical, the concentrations are inversely proportional to the vertical spreading of the plume, σ_z; the greater the downwind distance from the source, the greater the vertical dispersion and the lower the concentration. The sum of the two exponential terms in the vertical factor represents how far the receptor height, Z, is from the plume centerline in the vertical. The first term represents the direct distance H_e-Z, of the receptor from the plume centerline; the second term represents the eddy reflected distance of the receptor from the plume centerline, which is the distance from the centerline to the ground, H, plus the distance back up to the receptor Z, after eddy reflection. After doing the multiplication the above relations simplify to:

$$X(x,y,z:He)=\frac{\mathrm{Q}}{2\pi U\sigma y\sigma z}\left(\exp\frac{-y^2}{2\sigma y^2}\left[\exp\frac{-(H_e-Z)^2}{2\sigma^2}\right]+\exp\frac{-(H_e+Z)^2}{2\sigma_z^2}\right)$$

(equation 1)

Derivation of additional equations for specific situations for receptors at ground level, z = 0, equation 1 reduces to:

$$X(x,y,0:H_e)=\frac{Q}{2\pi U\sigma_y\sigma_z}\exp\frac{[-y^2]}{2\sigma^2_y}\exp\frac{[-H_e^2]}{2\sigma^2_z}$$

(equation 2)

In order to make concentration estimates directly beneath the plume centerline, y = 0, at ground level, z = 0, the equation further reduces to:

$$X(x,y,0:He)=\frac{Q}{2\pi U\sigma_y\sigma_z}\ \exp\ \frac{[\mathrm{-H_e}^2]}{2\sigma^2_z}$$

(equation 3)

To calculate concentrations at the plume centerline, y = 0, z = H_e, equation 3 becomes:

$$X(x,0,He:) = \frac{Q}{2\pi U\sigma_y\sigma_z}\left(1+\exp\frac{[-H_e{}^2]}{2\sigma^2{}_z}\right)$$

(equation 4)

To calculate concentrations along the plume centerline at ground level from a ground level release, y= 0, z = 0, H_e = 0, equation 4 becomes:

$$'X'(x,0,0:0) = \frac{Q}{2\pi U\sigma_y\sigma_z} \quad \textit{(equation 5)}$$

2.2 Modeling Parameters: In the course of modeling, the parameters considered were: the flare stack height (30m); exit velocity of gas (13m/s); flare stack diameter (0.85m); exit temperature of gas (1015^{O}C); average ambient air temperature between (26 - 30 ^{O}C); flare gas heat rate (873mmBtu/hr); natural gas heat value (48MJ/kg); average dominant wind speed in the area (1, 3, 5 and 8m/s) and the prevailing wind direction which is south-westerly (SW).

3. Results

Figures 2 – 9 show the concentration results and analysis of model outputs. Emission concentrations were more prevalent at closer range under the "very unstable atmospheric condition at wind speeds; 1m/s (4.5 – 6.5km), 3m/s (1.2 – 2.2km), 5m/s (0.9 – 1.4km) and 8m/s (0.5 – 1km), respectively (see Figs: 2, 3, 5 & 7). The higher the wind speed the closer the emission impact under that condition. However under the stable and neutral conditions, emission concentrations are at farther distances i.e., from 6km and over (Figs: 6, 8 & 9). In comparing the rates of dispersion in the atmospheric stability categories, the results clearly show the behavior of the plume in the different conditions under various wind speeds. At low wind speeds (1-3m/s), high concentrations are experienced from 0 to 8km, while at strong winds (5-8m/s), concentrations are high between 300m-1km. At higher wind speeds, the concentration of the pollutants decreases at increased distance (see Figs 2-9). This explains the consequence of turbulent diffusion on the pollutants as they travel downwind from the source. Unlike the unstable conditions, for stable conditions at lower wind speeds, there are no significant concentrations at receptors closer to the emission source as it is beyond 8km (Fig. 4). These stable conditions which are more prevalent at night could be as a result of radiation inversion at the earth surface in which stability of the atmosphere switches between the elevations of stacks. At elevated stacks above inversion, close to the ground the air is stable and this will inhibit dispersion around nearby receptors. Well above ground, the air is unstable and will cause the pollutants to mix with the air aloft, thereby inducing greater dilution. In this situation the ground will receive little or no surface impact; emissions will rather remain at the upper levels and be dispersed there. If eventually the stability of the atmosphere changes, it will affect those living downwind of the pollution source. The neutral condition also showed similar trend at lower wind speeds, but at higher wind velocity, concentrations would be prevalent from 5.3km and beyond (Figure 9). In the neutral set up, the atmosphere neither enhances nor inhibits mechanical turbulence.

Generally, buoyancy forces lift plumes and it takes some time to reach the ground (by bending and spreading). When there is no concentrations observable in the immediate vicinity of the emission source, then we can expect an increase for some distances as the plume touches the ground. In all the stability classes, ground concentration decreases according to the order: unstable > neutral > stable categories at lower and higher wind speeds (see all 2D outputs below). Stability assumes a critical role in determining the amount of turbulence in the atmosphere and thus directly affects the levels of dispersion. Turbulence and mixing can increase as well as decrease pollutants concentrations at certain points. In unstable conditions, ground level pollution is easily dispersed thereby reducing ground level concentrations. Elevated emissions, such as those released from a high stack, are returned more readily to ground level, leading to higher ground level concentrations and that is where emission pollution matters most. It should be noted that stable conditions means less atmospheric mixing and therefore higher concentrations around ground level sources, but better dispersal rates and so, lower ground level concentrations for elevated sources. Ground level sources are those according to U.S. EPA, defined for stacks between 0 - 10m, while elevated sources are those defined for stacks between 10 - 200m and above. This leads us to the fact that concentrations of pollutants also depend on stacks elevation as well as the rate at which pollutants are being emitted from the stacks. It should be noted that the emission source stack for this study is about 30m.

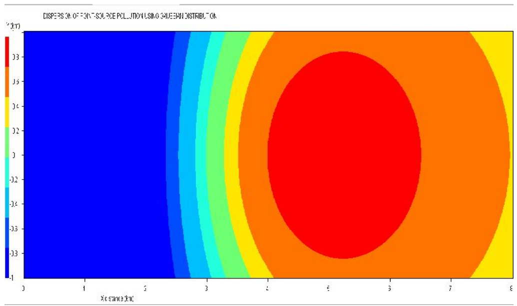

Figure 2: Very Unstable Atmospheric Condition at 1m/s Wind Speed

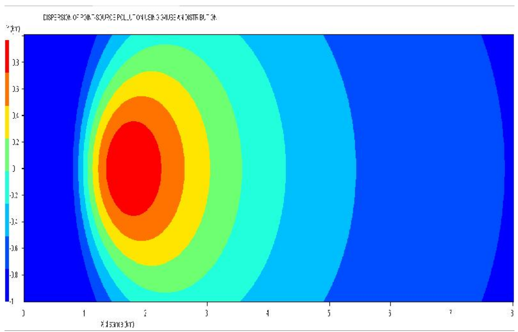

Figure 3: Very Unstable Atmospheric Condition at 3m/s Wind Speed.

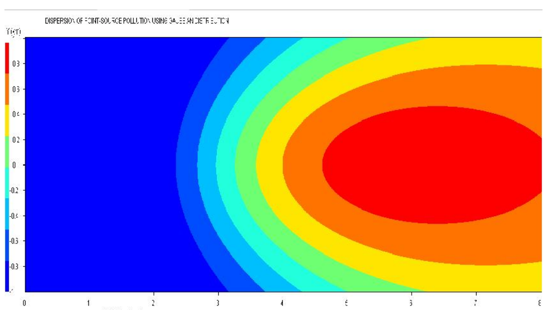

Figure 4: Slightly Unstable Atmospheric Condition at 3m/s Wind Speed.

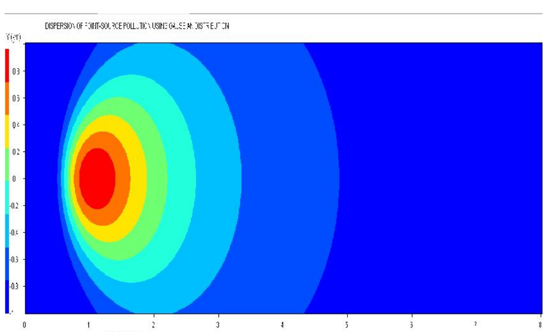

Fig. 5: Very Unstable Atmospheric Condition at 5m/s Wind Speed.

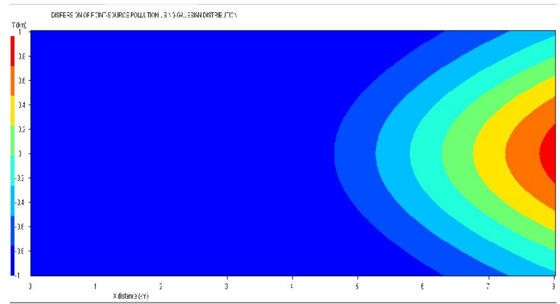

Fig. 6: Stable & Neutral Atmospheric Condition at 5m/s Wind Speed.

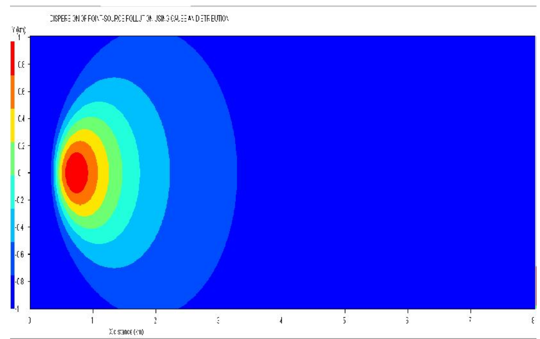

Figure 7: Very Unstable Atmospheric Condition at 8m/s Wind Speed.

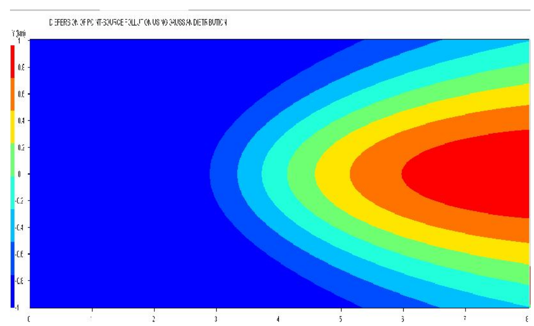

Figure 8: Stable Atmospheric Condition at 8m/s Wind Speed.

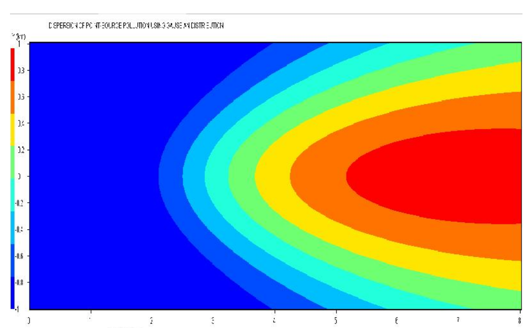

Figure 9: Neutral Atmospheric Condition at 8m/s Wind Speed.

4. Discussion

Field measurements show that the average wind speed in Idu Obosi is about 3 m/s. Extreme winds can be observed during squals and storms. The built-up area of the settlement begins at 300m from the flare point and luminous glare from the flare is felt at all times from every position in the settlement. The trajectary of Idu Obosi relative to the flare is illutrated in Figure 10. The choropleths in Figures 2 - 9 show that the entire Idu Obosi Town is well within the maximum impact range of 8 km obtained from the modelling outputs of this study for all atmospheric dispersion situations.

This study clearly demonstrates that meteorological factors assist in predicting the behavior of plumes that contain pollutants i.e., plume rise, transport and dispersion in the atmosphere. The dominant wind speed direction in the study area is south-westerly, meaning that pollutants will be transported to the north and north-eastern directions, except by night when it may reverse due to land breeze and during the dry (*Harmmattan)* season when the northeast trade wind persist.

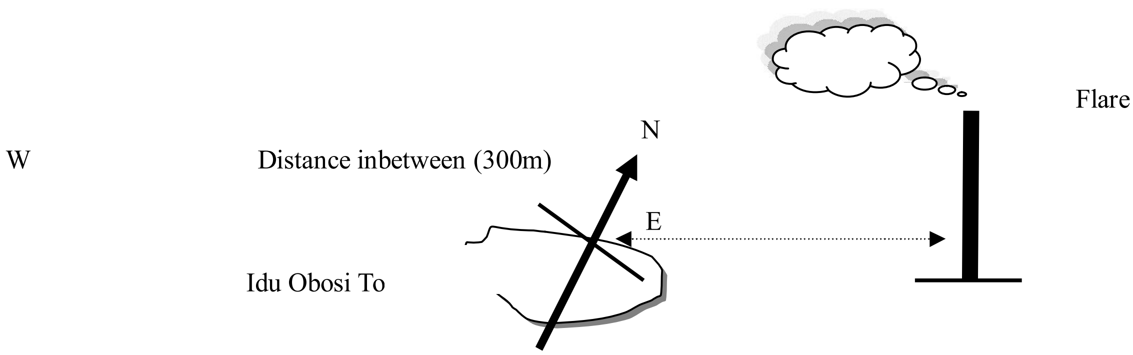

Figure 10: Trajectory of Idu Obosi to the Flare

The processing of non-associated gas or re-injection is more expensive than flaring. Gas flaring, as a wanton wastage of valuable resources, is necessarily linked with poverty, as utilization of the gas, which is otherwise flared, could improve the lots of the people. That is why, in furtherance of its poverty reduction policy, the World Bank Group, in active collaboration with the Government of Norway, commenced a global campaign for gas flaring reduction. The campaign, dubbed: *Global Gas Flaring Reduction Public-Private Partnership Initiative* (GFRPI) was launched formally at the World Summit on Sustainable Development (WSSD), Johannesburg, South Africa, on August 30, 2002. The aim of GFRPI, according to the World Bank press release issued at the formal launching, is "to support national governments, development agencies, and the petroleum industry in their efforts to reduce the environmentally damaging flaring and venting of gas associated with the extraction of crude oil." The initiative was put forward during a June 2001 Oslo Seminar hosted by Ann Kirsten Sydney who was then the Norwegian Minister for International Development. Subsequently, the initiative was informally launched by the Conference of the Parties (COP-7) under the United Nations Framework Convention on Climate Change (UNFCCC) in Marrakesh, Morocco. On April 15-16, 2003 another GPRPI conference was held at Oslo, Norway, where the stakeholder consultation phase of the initiative was concluded. Nigeria was among 25 other countries that attended the conference.

Gas flaring reduction activities are aimed at capturing the gas produced at the oil extraction source and channelling it to more useful outlets including power generation in industries and for use in households. The GFRPI enables private investment in pipelines and other infrastructure that makes this "capturing" possible. Already, the GFRPI has been working on specific gas flaring reduction projects in Russia, Indonesia, and Nigeria to demonstrate how carbon credit trading instituted by the Kyoto Protocol can improve the viability of gas flaring reduction projects. Other key activities of the partnership include improving legal and regulatory framework for investment in flaring reductions, improving international market access for gas and provision of technical assistance to develop domestic markets for the harnessed gas, and promote local small-scale use of gas. The main focus of the initiative would be Africa, and the Americas. The initiative, it seems, could also support other global initiatives geared towards addressing energy security especially for Nigeria and other developing countries (Malumfashi, nd).

5. Conclusions

The findings from this study have shown that gas flaring in Nigeria impact nearby settlements and may cause economic loss. Significant levels of emissions can emanate from a gas flare site with strong concentration within the vicinity of the source. The spread of these emissions in the atmosphere at any point in time depend on the effects of meteorological agents i.e., wind speed, wind direction, air temperature, relative humidity, rainfall, intensity of turbulence and mixing and atmospheric stability. The application of the AirWare Modelling software involves significant certainties that suggest a confidence in emission concentration impacts, on its wide use in assessing environmental problem and air pollution control. From the analysis it could be inferred that pollutants concentration would be greatest for receptors very close to emission sources (300m–– 1km) and better for receptors far away under unstable conditions due to turbulent factors. Also pollutants concentration under the neutral and stable conditions will be better at receptors close to the emission sources and worse at receptors far away from emission sources. This could be rife in the neutral conditions when an external force like the wind carries pollutants to ground level unpredictably. It should be noted that stack elevation and emission rates of pollutants can also play a role in bringing pollutants to ground level receptors. The taller the stacks and the lower the emission rates of pollutants, the better the dispersion, and vice-versa.

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