Advancement in Science and Technology Research
Vol. 5(2), pp. 9-36, November 2019
ISSN: 2437-1319
Full Length Research Paper

Modeling of gaseous pollutants dispersion of a fossil fuel-fired power plant at Omotosho, Ondo State, Nigeria

Rhoda Omolade Happiness[1], Blessing Ifeoluwa Ogunniran[2*] and Ayo Oluleye[3]

[1]Department of Meteorology and Climate Science, Federal University of Technology Akure, Ondo State, Nigeria.
[2]School of Environmental Science, Beijing Normal University, China.
[3]Department of Meteorology and Climate Science, Federal University of Technology Akure, Ondo State, Nigeria.

Accepted 22 October, 2019

ABSTRACT

The American Meteorological Society (AMS) and U.S. Environmental Protection Agency (EPA) Regulatory Model (AERMOD model) has been used to assess the ground level concentrations of carbon dioxide (CO), oxides of nitrogen (NO_X), particulate matter less than 10.0 microns in diameter (PM_{10}) and sulphur dioxide (SO_2). The purpose was to predict and assess the effect of these flue gases on airshed from an Integrated Oil and Gas Project (IOGP) in the Omotosho Power Plant. The emission of five elevated point sources for criteria air pollutants were considered with six different scenarios. Both natural gas-fired and diesel (AGO) fired equipment were used in the prediction of the ground level concentration of the pollutants. The model outputs show generally maximum ground level concentrations at the north east of the source points compared to the receptor points. CO concentration is greatest in all scenarios followed by NO_X and then PM_{10} and then SO_2. Maximum ground level concentration for 1, 8 and 24 h periods for CO, PM_{10}, SO_2 and NO_X were all below the guidelines limit, Federal Ministry of Environment in Nigeria (FMNEV), Environmental Guidelines and Standards for Petroleum Industries in Nigeria (EGASPIN) and World Bank Limit. Also the results show that scenarios which uses AGO fuel have higher emissions than natural gas fuel in all cases this is unsafe and unhealthy for human. Summarily, the use of AGO fuel should be minimized for a safe environment.

Keywords: Fossil fuel-fired power plants, gaseous pollutants, dispersion, AERMOD.

*Corresponding author. E-mail: aoluleye@futa.edu.ng.

INTRODUCTION

Fossil fuels are burnt in power plant or generator that generates electricity, in many industrial plants and home furnaces. It has been estimated that about 75% of all air pollutants come from burning fossil fuels and biomass (Bello, 2013).

The remaining pollutants come mainly from industrial processes other than fuel burning, agricultural fires and the evaporation of solvents. Studies conducted by Bello (2013) revealed that transportation is the largest sources of human-caused air pollution in most cities, where it accounts for over 55% of air pollution. The second largest source is fuel combustion in stationery sources such as power plants and factories which account for 20%. Industrial processes other than fuel burning accounts for 10%, solid waste disposal accounts for 5%. Air is being contaminated by the ever-increasing amounts of dust, smoke and other particulate matter. Most of the industries emit highly toxic fumes and smoke making the air unsuitable to all living beings and the species with a lower resistance die. Burning of large amounts of fossil fuels results in addition of large amounts of carbon dioxide, sulphur dioxide and particulate matter. There is a high concentration of sulphur particle in many industrial regions and these particles combine with rainwater to form sulphuric acid. High concentrations of both carbon dioxide and carbon monoxide are harmful to the living beings and their concentrations in many urban areas have assumed dangerous levels (Bello, 2013).

Air pollution may be defined as a situation in which substances that result from anthropogenic activities are present at concentrations sufficiently high above their normal ambient levels to produce a measurable and undesirable effect on humans, air shed, animals, vegetation, or materials (Seinfeld and Pandis, 2006). Air pollutants can cause serious problems when large–scale industrial complexes are located close to residential areas. In particular, exposure to such air pollutants may adversely affect human health (Ma et al., 2013).

Carbon dioxide (CO_2) is a good indicator of how much fossil fuel is burned and how much of other pollutants are emitted as a result.

Large number of deaths and other health problems associated with particulate pollution was first demonstrated in the early 1970s and has been reproduced many times. Pollution resulting from PM is estimated to cause 22,000 to 52,000 deaths per year in the United States (from 2000), contributed to approximately 370,000 premature deaths in Europe during 2005, and 3.22 million deaths globally in 2010 per the global burden of disease collaboration.

The importance of the evaluation of air pollution at regional scale has been evident in recent years. Many studies have shown that the major impacts on human health from many of the primary pollutants such as sulfur and nitrogen oxides are not caused directly, but by the sulfate and nitrate aerosols in which they are transformed during their dispersal at regional scale (Spadaro, 1999). To evaluate the air pollution from a source, it is imperative to consider both their emissions (concentration, temperature and flow rate of the exhaust gas streams, release height, etc.) as well as the contribution of these emissions on air quality (concentration of pollutants in the air). An air shed should be considered as having poor air quality if nationally legislated air quality standards or World Bank Guidelines are exceeded significantly.

Air pollution models are very indispensable in regulatory, research and forensic application because it is the only method that quantifies the deterministic relationship between emissions and concentration deposition (Oluleye, 2012).

Over the years air pollution model has been a very effective numerical research tool in assessing the causes of air quality problems which includes negative effects on health in area of high concentrations of power plant. Air pollution is caused by increase in emission of gaseous pollutants concentration on the environment.

Oil and gas provide the major global source of energy. The exploration of the fossil fuel generates a lot of concerns for the environment because of its hazardous effect. Pollution resulting from uncontrolled flaring of gas and burning of oil has environmental, economic and political consequences (Oluleye, 2012).

A fossil fuel power plant is a system of devices for the conversion of fossil fuel energy to mechanical work or electric energy. Fossil fuel-fired power plants are the largest source of Nigeria CO_2 emissions. To generate electricity, fossil fuel-fired power plants use natural gas, petroleum, coal or any form of solid, liquid or gaseous fuel derived from such materials (USEPA, 2000).

When fossil fuels are burned they create different types of air pollution problems. Besides creating particulate matter, burning fossil fuels creates smog. Smog makes the air look brown and dirty and can make people sick e.g. asthma, cancer, if they spend too much time outside breathing it in, Burning fossil fuels also creates dangerous gases that trap heat from the sun and make the planet too warm. This is called global warming and it makes the weather, or climate, change in serious ways.

Fossil fueled-fired power plants are major emitters of carbon dioxide (CO_2), a greenhouse gas which according to a consensus opinion of scientific organizations is a contributor to global warming.

Among the gases emitted when fossil fuels are burned, one of the most significant is carbon dioxide, a gas that traps heat in the earth's atmosphere. Over the last 150 years, burning fossil fuels has resulted in more than a 25% increase in the amount of carbon dioxide in our atmosphere. Fossil fuels are also implicated in increased levels of atmospheric methane and nitrous oxide, although they are not the major source of these gases.

The pollution that forms downwind of a power plant depends on shifting factors in the air. Pollution dispersion processes are strongly related to the patterns of flow and turbulence in these layers in the lower atmosphere. Air pollutants are being let out into the atmosphere from a variety of sources, and the concentration of pollutants in the ambient air depends not only on the quantities that are emitted but ability of the atmosphere either to absorb or disperse these pollutants (Jayamurugan et al., 2013).

Sources of pollution

Air pollution may be classified into two types according to the nature of formation: primary pollutants which are emitted from their sources directly to the atmosphere such as industry, power plants and secondary pollutants which results from the chemical reaction between the primary pollutants and other substances in the air. Examples of primary pollutants are sulphur dioxide (SO_2), nitrogen oxide (NO), and carbon monoxide (CO).

Needless to say, Nigeria is not remotely close to the scale of industrial activity that makes China the factory of the world. Still, when it comes to the burning of fossil fuel, the chief source of air pollution in Nigeria, Lagos, will top Shanghai. Unregulated emissions from the diesel and petrol engines of millions upon millions of cars, buses, trucks and generators lead to astronomically high levels of carbon and sulphur oxides and other volatile organic compounds (VOCs) in the air (Ifewodo, 2013).

Emission of gaseous pollutants from power plants

The amount and nature of gaseous pollutants emissions depends on factors such as the fuel (e.g., coal, fuel oil, natural gas, or biomass), the type and design of the combustion unit (e.g., reciprocating engines, combustion turbines, or boilers), operating practices, emission control measures (e.g., primary combustion control, secondary flue gas treatment), and the overall system efficiency. For example, gas-fired plants generally produce negligible quantities of particulate matter and sulfur oxides, and levels of nitrogen oxides. More significantly, natural gas turbine facilities are now understood to have very low particulate emissions, as there is no active mechanism for their generation from methane combustion.

The industrialization and urbanization bring with them the unwanted adverse air pollutants (Varma et al., 1994). The major anthropogenic sources of air pollutants are industrial emissions, domestic fuel burning, and emissions from power plants.

Emissions of SO_2 are caused by burning fossil fuels, mining coal containing some sulfur, emissions of particulates occur most heavily when combustion is inefficient. Reduction in air pollution is achieved primarily by stationary combustion sources, such as fossil fueled power plants, industrial furnaces and steel mills. Most oxides of sulfur and nitrogen are emitted from tall stacks at power plants in order to increase the dispersion and dilution of the stack gases.

The global emission of Nitrogen Oxides concentrations was mostly from anthropogenic sources especially during fossil fuel combustion process (Oliver et al., 1990). NO_X is a primary pollutant which originates from natural process or anthropogenic activity (Ocak and Turalioglu, 2008). Nitric oxide (NO) is produced by combustion. Nitrogen dioxide (NO_2), which has greater health effects, is a secondary pollutant created by the oxidation of NO under conditions of sunlight, or may be formed directly by higher temperature combustion in power plants or indoors from gas stoves (WHO, 1987a).

Power plants remove particulate from the flue gas with the use of a bag house or electrostatic precipitator. Several newer plants that burn coal use a different process, Integrated Gasification Combined Cycle in which synthesis gas is made out of a reaction between coal and water. The synthesis gas is processed to remove most pollutants and then used initially to power gas turbines. Then the hot exhaust gases from the gas turbines are used to generate steam to power a steam turbine. The pollution levels of such plants are drastically lower than those of "classic" coal power plants.

In the past several years, more and more cities around the globe are experiencing problems from air pollutants emitted from industrial processes. The nature and significance of air quality issues depend on many factors. Such factors include size of city, physical and chemical industrial processes, meteorological processes, geographical features and social factors (Pires et al., 2008). To improve air quality in cities, a need for air pollution control and prediction of trend is urgent. In addition, short term forecasting of air quality assessment is crucial since it assists in taking preventive and evasive action during episodes of elevated air pollution (Makra et al., 2010).

Acid deposition occurs when emissions of sulfur dioxide and nitrogen oxides in the atmosphere react with water, oxygen, and oxidants to form acidic compounds. These compounds fall to the earth in either dry form (gas and particles) or wet form (rain, snow, and fog) (National Air Quality, 2002).

Due to transport properties, emissions are rarely retained within the point of release, they are transported through plume. To study the effects of pollutants at distances away from the source, dispersion models are commonly employed. Air dispersion modeling uses mathematical formulations to quantify the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, dispersion models can be used to predict concentrations at some selected downwind receptor locations. Such models are widely used in the management of impact of pollutant emissions on the environment (Holmes and Morawska, 2006; Kesarkar et al., 2007; Abdelrasoul et al., 2010).

Some effects of air pollution emission

A variety of chemicals are released into the atmosphere when fossil fuels are burnt. Since air is needed for staying alive, air pollution has a direct impact on human health (EPA, 2001).

These are the effects of air pollution on health:

- Breathing polluted air puts human being at a higher risk for asthma and other respiratory diseases.
- Air pollutants are mostly carcinogens and living in a polluted area can put human at risk of Cancer.
- Coughing and sneezing are common symptoms.
- Damages the immune system, endocrine and reproductive systems.
- High levels of particle pollution have been associated with higher incidents of heart problems.
- The burning of fossil fuels and the release of carbon dioxide in the atmosphere are causing the Earth to become warmer known as global warming (EPA, 2001).

Table 1 shows the anthropogenic sources and the related environmental effects and health effects of common

Table 1. Sources and effects of common air pollutants.

Pollutant	Anthropogenic sources	Health effects	Environmental effects
Ozone (O_3)	Secondary pollutant formed by chemical reaction of VOCs and NOx in the presence of sunlight	Breathing problems, reduced lung function, asthma, irritates eyes, stuffy nose, reduces resistance to colds and infections, premature aging of lung tissue	Damages crops, forests, and other vegetation; damages rubber, fabric, and other materials; smog reduces visibility
Nitrogen oxides (NOx)	Burning of gasoline, natural gas, coal, oil (Cars are a major source of NOx)	Lung damage, respiratory illnesses, ozone (smog) effects	Ozone (smog) effects; precursor of acid rain which damages trees, lakes, and soil; aerosols can reduce visibility Acid rain also causes buildings, statues, and monuments to deteriorate
Carbon monoxide (CO)	Burning of gasoline, natural gas, coal, oil	Reduces ability of blood to bring oxygen to body cells and tissues	
Volatile organic compounds (VOCs)	Fuel combustion, solvents, paint. (Cars are a major source of VOCs.)	Ozone (smog) effects, cancer, and other serious health problems	Ozone (smog) effects, vegetation damage
Particulate matter	Emitted as particles or formed through chemical reactions; burning of wood, diesel, and other fuels; industrial processes; agriculture (plowing, field burning); unpaved roads	Eye, nose, and throat irritation; lung damage; bronchitis; cancer; early death	Source of haze which reduces visibility Ashes, smoke, soot, and dust can dirty and discolor structures and property, including clothes and furniture
Sulfur dioxide (SO_2)	Burning of coal and oil, especially high-sulfur coal; industrial processes (paper manufacturing, metal smelting)	Respiratory illness, breathing problems, may cause permanent damage to lungs	Precursor of acid rain, which can damage trees, lakes, and soil; aerosols can reduce visibility. Acid rain also causes buildings, statues, and monuments to deteriorate
Lead	Combustion of fossil fuels and leaded gasoline; paint; smelters (metal refineries); battery manufacturing	Brain and nervous system damage (esp. children), digestive and other problems. Some lead-containing chemicals cause cancer in animals	Harm to wildlife and livestock
Mercury	Fossil fuel combustion, waste disposal, industrial processes (incineration, smelting, chlor-alkali plants), mining	Liver, kidney, and brain damage; neurological and developmental damage	Accumulates in food chain

Source: Leonardo (2013).

pollutants.

Pollution dispersion transport models

Determination of air pollution can be done with the use of various dispersion models or direct observation. Dispersion modeling describes the transport and dispersion of air pollutants, as well as chemical and physical processes within the plume. Specifically, air quality models have proven useful for determining the spatio temporal distribution of air pollutants and for developing emission control policies that allocate limits to air pollutant emissions (Holmes and Morawska, 2006; Zhang et al., 2010; Ma et al., 2013). Many researchers use Gaussian models such as the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), and the California Puff model (CALPUFF) to evaluate air pollution phenomenon. CALPUFF is a non-steady state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal. It can be applied for long-range transport and for complex terrain.

A commonly used regulatory air pollution dispersion model is the American Meteorological Society and U.S. Environmental Protection Agency Regulatory Model (AERMOD) (Perry et al., 2005). AERMOD has been used for predicting the dispersion of a number of pollutants such as SO_2 and NO_x from power plant (Ding, 2012), mercury from silver smelting (Hagan et al., 2011) and particulate matter (Kesarkar et al., 2007). It is a steady–state Gaussian plume dispersion model aimed at short–range (<50 km) air pollution dispersion from point, line area and volume sources (Cimorelli et al., 2003; Perry et al., 2005). AERMOD (Lakes Environmental, Ontario, Canada) incorporates meteorological data pre–processing (AERMET) and uses modern knowledge on planetary boundary layer theory, which serves as a replacement to Pasquill–Gifford stability class– based plume dispersion models such as ISC–PRIME and ISCST3 (Peters et al., 2003). AERMOD has been promulgated by the US EPA as a preferred air dispersion model to replace the ISCST3 (Lee and Keener, 2008). AERMOD's concentration algorithm considers the effects of vertical variation of wind, temperature and turbulence profiles. These profiles are represented by equivalent values constructed by averaging over the planetary boundary layer (PBL) through which plume material travels directly from the source to the receptor (Cimorelli et al., 2003).

The model uses the boundary layer parameters in conjunction with meteorological measurements to characterize the vertical structure profiles as above. In mountainous terrain, AERMOD divides and streamlines plume flow over and around hills, which greatly increases its accuracy to model in complex terrain (Langner and Klemm, 2011). In addition, Perry et al. (2005) observed that AERMOD's good performance in mountainous terrain is also due to the detailed inclusion of boundary layer vertical structure information. AERMOD contains building downwash, plume rise and terrain treatment algorithms (EPA, 2000). For the purpose of this study AERMOD model has been adopted.

AERMOD Description

The AERMOD air dispersion model is USEPA's official air dispersion model for regulatory use and was developed by the AERMIC (The **A**merican Meteorological Society/**E**PA **R**egulatory **M**odel **I**mprovement **C**ommittee) work group.

AERMOD, AERMET (AERMOD Meteorological Preprocessor) and AERMAP (AERMOD Terrain Preprocessor), AERMET is a meteorological pre-processor that calculates meteorological parameters and passes them to AERMOD. AERMAP is a terrain pre-processor that calculates terrain elevations above mean sea level and passes them to AERMOD.

Several studies have been conducted to evaluate the AERMOD model performance using various statistical parameters (Paine et al., 1998; Perry et al., 2005; USEPA, 2012). Evaluations have shown that the AERMOD model performance is generally good when tested across wide range of scenarios. Individual model predictions usually differ from corresponding observations because the model cannot include all of the variables that affect the observation at a particular time and location.

AERMOD is a steady-state Gaussian plume model which can simulate dispersion from multiple sources using up-to-date concepts regarding boundary layer characterization and dispersion. When the effects of complex terrain are required, the AERMAP terrain pre-processor is used. After the AERMAP is analyzed then the terrain values are then passed to the AERMET.

AERMOD that was used to model the gaseous pollutants can be used for predicting the concentrations of various pollutants emitted by point, line and area sources. This model is typically used for large areas (Faulkner et al., 2007; Hanna et al., 2006; Jampana et al., 2004; Kumar et al., 2006; Stein et al., 2007; Touma et al., 2007) or stationary sources (Orloff et al., 2006; Seigneur et al., 2006). Kesarkar et al., (2007) used AERMOD to estimate PM_{10} concentrations over the city Puna in India and found that the model generally underestimated PM_{10} concentrations except for residential areas. Nitrogen oxides are of concern because of their direct effects and because they are precursors for the formation of ground-level ozone (Zhang et al., 2008). Although the model has not been widely used in predicting near-road pollutant concentrations, EPA recommends AERMOD to evaluate near-road concentrations.

Figure 1 shows explicitly the flow in AERMOD modeling and also how the meteorological and geographical data are analyzed to predict the ground level concentration on airshed and its direct impact on the environment.

Modelling process using AERMOD model

The process of AERMOD dispersion modeling, firstly involves gathering specific information in relation to the emission sources considered. These include:

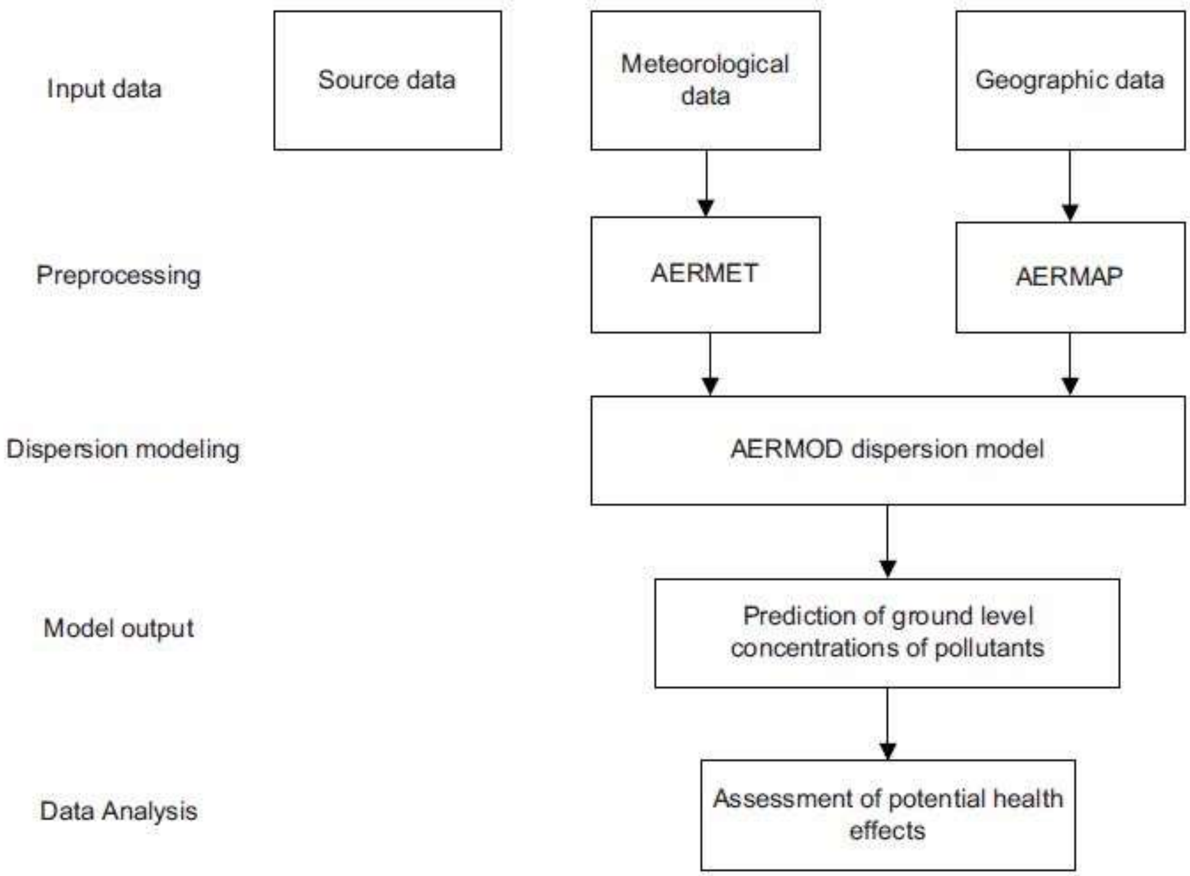

Figure 1. Flow in AERMOD modeling system.

Source information: Emission rate, exit temperature, volume flow, exit velocity. Site information: Site building layout, terrain information, land use data; Meteorological data: Wind speed, wind direction, temperature, and cloud cover; Receptor information*:* Locations using discrete receptors and/or gridded receptors.

The model uses this specific input data to run various algorithms to estimate the dispersion of gaseous pollutants between the sources and receptors. The model output is in the form of a predicted time-averaged concentration at the receptor. In this project work, post-processing was carried out to produce percentile concentrations and contour plots was prepared for reporting purposes to know how the pollutants dispersed over the study area considered.

Applications, benefits and limitations of dispersion modelling

Air dispersion modelling provides a cost-effective means for assessing the impact of air emission sources, the major focus of the study is to determine compliance with the relevant ambient air quality standards e.g FMNEV, EGASPIN, World Bank Limit.

Models can also be used for planning, design and management of emissions from installations on Power Plants.

AERMET meteorological pre-processor

The AERMET meteorological pre-processor produces two types of meteorological input files required by AERMOD, a surface file which contains various meteorological and surface scalar parameters, and a profile file which consists of meteorological data at more than one height for use when undertaking an on-site monitoring programme.

The input requirements for AERMET include surface characteristics (such as surface roughness, Bowen ratio, and Albedo) and hourly meteorological data (wind speed, wind direction, cloud cover, and temperature).

AERMET requires user input data on site-specific surface characteristics. Recent guidance by the USEPA regarding the implementation of AERMOD provides the methods for determining the correct surface characteristics required by AERMET.

AERMAP terrain pre-processor

The AERMAP terrain pre-processor was used to prepare the terrain information required by AERMOD for complex terrain scenarios. AERMAP sets a hill height scale, which is the height that has the greatest influence on dispersion, for each individual source and receptor modeled by AERMOD. AERMAP requires terrain information for the modeling domain in the form of a Digital Elevation Model (DEM) file.

The analysis of the proposed project effects on the air shed takes into consideration Criteria Air Contaminants (CACs). Criteria air contaminants relevant to this proposed Project include particulate matter (PM), nitrogen oxide (NO_2), carbon monoxide (CO), and sulphur dioxide (SO_2). These are primary indicators of air quality and are associated with human health impacts (primarily through inhalation) and environmental impacts, including aesthetic, visibility, and toxic effects.

AERMOD requires the input of two meteorological input files. A surface file and a profile file. The surface meteorological data file consists of the following input variables:

- Sensible heat flux (W/m^2)
- Surface friction velocity, u* (ms^{-1})
- Convective velocity scale, w* (ms^{-1})
- Vertical potential temperature gradient in the 500 m layer above the PBL
- Height of the convectively-generated boundary layer (m)
- Height of the mechanically-generated boundary layer (m)
- Monin-Obukhov length, L (m)
- Surface roughness length, z_0 (m)
- Bowen ratio
- Albedo
- Wind speed (m/s) used in the computations
- Wind direction (degrees) corresponding to the wind speed above
- Height at which the wind above was measured (m)
- Temperature (K) used in the computations
- Height at which the temperature above was measured (m)
- Precipitation code
- Precipitation rate (mm/hr)
- Relative humidity (%)
- Station pressure (milli bars)
- Cloud cover (tenths)

The contents of the profile meteorological data file are as follows:

- Measurement height (m)
- Wind direction for the current level (degrees)
- Wind speed for the current level (m/s)
- Temperature at the current level (^oC)
- Standard deviation of the wind direction (degrees)
- Standard deviation of the vertical wind speed (m/s)

There is a global concern over the environmental status of powered plants and their prospective impact on air shed. Implementation of control measures that will guarantee availability of safer air quality in the area can only be achieved if possible source of air pollutants are identified in every major project proposed for the area with potential ground level concentrations.

An additional benefit of the control of these air pollutants is the prevention of possible secondary air pollutants that can be formed within the atmosphere. These are some of the issues set to be addressed by the emission inventory and dispersion modeling carried out in the study area.

The concentrations of these pollutants in the exhaust gases are a function of firing configuration, operating practices, and fuel composition.

METHODOLOGY

Study area

This research work was carried on Omotosho Power Plant, Okitipupa, Ondo State, Nigeria. The plant was located between Longitudes, Latitudes 4.69°N, 6.72°E and Latitudes Longitude 6.74°E, 4.72°N. The studied power plant has a capacity of 512.8 MW (ISO) and a configuration of four gas turbines.

The area of Omotosho power plant is 0.15 km^2. Figure 2 shows the study area of the power plant, partly covered with afforestation project. The climate condition of Omotosho Power Plant follows the pattern of South Western Nigeria, where the climate is influenced mainly by the rain bearing Southwest monsoon wind from the ocean and the dry north west winds from the Sahara Desert. High temperatures and high humidity also characterize the climate. There are two distinct seasons, the rainy and dry seasons. The rainy season occurs between April and October with bimodal peak in July and September; while the dry season occurs between November and March while the month of June receives the highest rainfall of between 1500 and 3000 m with a short break in August. Raining seasons last for about seven months (April to October). The rainfall is about 1284 mm. The dry season which last from Nov to March is characterized by the Northeast trade winds Temperature is high reaching an annual mean of 28°C. Relative humidity is high throughout the year and rarely goes beyond 60% (NIMET, 2012). The study area is classified as rural.

Meteorology and terrain parameters for the model

Hourly averaged meteorological variables were supplied to AERMET for processing which was later passed to AERMOD for the modeling exercise. These configurations include rural dispersion coefficients as well

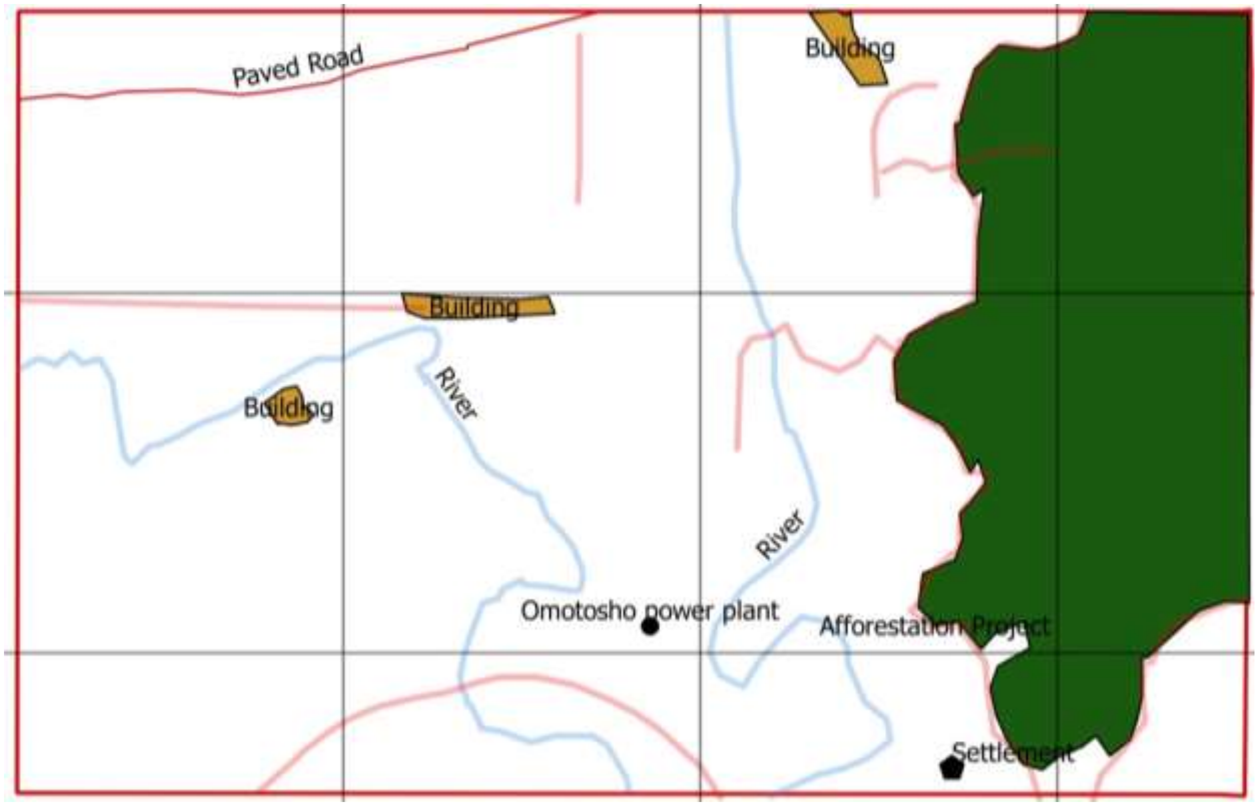

Figure 2. Location of Omotosho Power Plant, its neighboring settlements and infrastructure.

as simple topography. The elevation of the different sources and receptor ranging are considered from 79 to 100 m. The model has the capacity to use hourly sequential preprocessed meteorological data e.g. wind speed, wind direction, temperature, precipitation, relative humidity, cloud cover etc to estimate concentrations of pollutants at receptor locations at different time scales ranging from 1 h to 12 months for the purpose of this study (1, 8 and 24 h) . AERMOD requires upper air sounding data including atmospheric pressure, dry bulb temperature, dew point temperature, and wind direction and wind speed at Omotosho power plant.

Model version

The version 151811 of the AERMOD model was used in this modeling exercise. It is currently the latest version of the model that has been approved by the US Environmental Protection Agency (USEPA, 2015).

There are 5 sources and 15 receptors represented on different locations on the modeling domain.

Point sources

The point source is the most common type of source that is modeled in the modeling analyses. Emissions from point sources are released to the atmosphere through well-defined stacks, chimneys, or vents.

i. Source parameters

Point sources (stacks or vents) are the most common source type from industrial installations. In order to model point sources an accurate determination of the following information will be required:

Emission rate (typically in g/s) – emission rates are directly proportional to modeled concentration (for inert pollutants) and thus any errors in emission rates will feed directly through to the final result;

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. In most cases, emission factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category.

ii. Stack parameters

- Temperature of release (in K or °C) — the exit temperature will be important in the determination of plume rise and thus errors in exit temperature for buoyant plumes may lead to significant errors in modeled results;
- Stack diameter (in m) – the inner diameter of the stack;
- Stack height (in m) – this should be the height above the stack base elevation;
- Stack coordinates (in m) – either in UTM, ITM or Irish Grid or using relative grid coordinates. Whichever co-ordinates are used they should be consistent across all input parameters (terrain, sources, buildings etc.);
- Stack exit velocity (in m/s) – this should be based on the actual conditions of release, i.e. actual temperature, moisture and oxygen content (if relevant) or stack exit volume flow rate (in m3/s). (Any corrections for temperature, pressure, etc. should be applied separately to calculate mass emissions);
- Stack base elevation (in m) – important when terrain is a factor.

iii. Source emissions

Air emissions are emitted from point sources (large stationary such as fossil fuel fired power plants, smelters, industrial boilers) and non-point (area, on-road, non-road mobile and biogenic sources.

Air pollutants of concern have been selected for detailed impact assessment involving dispersion modeling using the following criteria:

i. The level of concern with reference to health effects (relates to ambient air quality objectives);
ii. Probability of occurrence of the substance at higher concentrations;
iii. Expected ground level concentrations with reference to the monitor detection limit.

The required meteorology data for AERMOD are surface data (hourly values) that describe conditions closer to ground level and upper air data (hourly values) that describe conditions higher in the atmosphere. Surface data consist of wind direction (degrees from true north), wind speed (m/s), dry bulb (ambient air) temperature (°C), dew point temperature (°C), total and opaque cloud cover (tenths), cloud ceiling height (m), station pressure (millibar), hourly precipitation amount (hundredths of inches) and relative humidity (%). Upper air data are required to determine convective mixing height (m). Mixing height is defined as the height to which the lower atmosphere will undergo mechanical or turbulent mixing, producing an early homogeneous air mass. Boundary layer parameters used by AERMOD, which are required as input to the AERMET processor, include Albedo, Bowen ratio, and Surface roughness. These parameters were determined by examining a 3 km radius area surrounding the study area in accordance with the USEPA (2005b).

Modeling method

Power plant configuration

The studied power plant has a capacity of 512.8 MW (ISO) and 451 MW (Net), power plant located in Okitipupa, Ondo State that employs pulverized gas technology. The power plant has a configuration of four gas turbines (GE Frame 9E Gas Turbines).

The Omotosho Power Plant is an open cycle gas turbine power plant built to accommodate future conversion to combined cycle gas turbine (CCGT) configuration.

Emission inventory

This study considered emissions from equipment associated with the proposed plant which require combustion activities for operation. The equipment identified were within the Processing system of the Power Plant and include fired heaters, gas turbine driven compressors and gas turbines required for power generation. The Processing system will have flares that will operate intermittently as shown in (Table 2).

Those with estimates include anticipated emissions from the compressors and power generators when diesel (AGO) is used as alternate fuel.

Table 3 summarizes the anticipated emissions from identified source and these serves as key inputs into the modeling activity. The required time averages (1, 8 and 24 h) were then computed from the raw data that was analyzed from the AERMOD model. Surfer is a grid based contour program. Gridding is the process of using original data points in an XYZ data file to generate calculated data points on a regularly spaced grid. Interpolation scheme estimate the value of the surface at locations where no original data exists, based on the known data values. However, Krigging interpolation scheme was used. Krigging is one of the more flexible methods and is useful for gridding almost any type of data set. With most data sets, Krigging with a linear variogram is quite effective. Krigging generates the best overall interpretation of most data sets

Dispersion modeling of pollutants for different scenarios

For a detailed assessment of the dispersion model in this study, six different scenarios of facility operation and fuel types evaluated in emission sources as shown in Table 4 were:

Table 2. Major sources of emissions and parameters used as input to the air dispersion model (AERMOD).

S/No	Emission source	Fuel consumption (kg/hr)		Stack parameters				Location	
		Gas fuel	AGO	Ht. (m)	Dia. (m)	Temp (k)	Exit Vel. (mls)	X_p (m)	Y_p (m)
1	Fired heater	3865	-	20	1.5	493	12.5	0	507
2	Atmospheric flare	2798	-	110	1.25	1273	20	492	435
3	AG compressor	2499	2774	11.4	1.14	780	14	101	163
4	Power generator turbine	2499	2774	11.4	1.14	758	22	101	225

Table 3. Computed air pollutants from the identified sources based on the type of fuel that was used for the various scenarios.

Source	From natural gas				From AGO			
	NO_X	CO	SO_2	PM_{10}	NO_X	CO	SO_2	PM_{10}
Fired heater	2.1	1.77	-	0.16	34	1299	1.7	2.1
Atmospheric flare	624	3400	-	-	-	-	-	-
AG compressor	5.6	2.7	-	-	24	932	1	1.5
Power generator turbine	7.3	1.8	-	-	24	932	1	-

Table 4. Emissions cases of each modeling scenario.

Scenario	Emission sources	Number included	Pollutant considered
1	Fired heaters Atmospheric flare Gas turbine driven AG compressor	1-NG fired 1-NG fired 1-NG fired	CO, NO_X, PM_{10}
2	Atmospheric flare Gas turbine driven AG compressor Power generator turbine drivers	1-NG fired 1-NG fired 1-NG fired	CO, NO_X, PM_{10}
3	Fired heaters Power generator turbine drivers	1-NG fired 1-NG fired	CO, NO_X, PM_{10}
4	Fired heaters Atmospheric flare Gas turbine driven AG compressor	1-AGO fired 1-AGO fired 1-AGO fired	SO_2, CO, NO_X, PM_{10}
5	Atmospheric flare Gas turbine driven AG compressor Power generator turbine drivers	1-AGO fired 1-AGO fired 1-AGO fired	SO_2, CO, NO_X, PM_{10}
6	Fired heaters Power generator turbine drivers	1-AGO fired 1-AGO fired	SO_2, CO, NO_X, PM_{10}

Scenario 1: It is assumed that three of the point sources of emission, fired heater, atmospheric flare and Gas Turbine-driven AG compressor are working in the system while the power generator turbine-drivers is shut down. In this scenario, the natural gas is assumed to be the fuel of consumption.

Scenario 2: The power plant is designed with one atmospheric flare, one gas turbine-driven AG compressor and one power generator turbine drivers while the fire heater not in use in this scenario. Natural gas is the fuel assumed to be in use.

Scenario 3: The atmospheric flare is used only during emergency cases, therefore in this scenario the atmospheric flare and the gas turbine driven AG Compressor is shut down while fired heaters and Power generation turbine drivers is in use. The fuel considered for combustion is the natural gas.

Scenario 4: In this Scenario, the operating condition were assumed similar to that of Scenario 1 but with the fuel considered for combustion as the AGO.

Scenario 5: In this Scenario, the operating condition were assumed similar to that of Scenario 2 but with the fuel considered for consumption as the AGO.

Scenario 6: In this Scenario, the operating condition were similar to that of scenario 3 but with the fuel used for combustion as the AGO.

RESULTS AND DISCUSSION

The objective of this study is to assess the contribution of fossil fuel powered plant (flue gases) to airshed and the AERMOD model is used to ascertain the concentration within 0 to 50 km. The location of the nearest settlement within the area of concentration of the powered plant falls within 0.15 km. Pollution dispersion for the facility was simulated for six scenarios with different facility.

Wind rose for the study area

The Study area has two predominant surface wind sources, which include winds from the southerly directions coming across from the Gulf of Guinea and overland winds coming principally from over fresh water swamps.

Figures 3 and 4 shows the wind rose based on two years meteorological observations at Douala. This is consistent with the winds observed at the study area. Also for other meteorological parameters that affect dispersion, such as temperature and cloud cover, Lagos meteorological observations were used in this study.

Lack of upper air observations in Ondo State weather station made it impossible to have data whose input would have been useful in this study. However, there are two locations nearby the region, Lagos and Douala. The surface data was gotten for Lagos and Cameroon upper air data for Douala. Both Lagos and Douala are on a south-facing coast with the winds having prevalence for a southwesterly direction same as the study area (Ondo State).

In Omotosho power plant, the average hourly wind speed during the wet season is 3.85 m/s the calm condition being just 21% wind speed characteristics over the area (Figure 3). Wind speed determines the amount of dispersion of pollutants and meteorological conditions can exert a large impact on various air pollutants concentrations and often mask long term trend in air pollutants concentrations (Turki, 2014). The diagram also shows the south westerly winds are predominant in the area.

In Omotosho power plant the average hourly wind speed is 0.783m/s with the calm condition being the major wind speed characteristics over the area (Figure 4). It is also observed that the North Easterly trade winds are predominant over the area during dry season.

Scenarios and results

Four critical pollutants (NO_X, SO_2, PM_{10} and CO) released from all emitting sources and receptors were considered in this study for investigation. NO_X is assumed to include all oxides of Nitrogen. The composition of NO_X from the point of release is mainly nitrogen mono oxide (NO) the gas is quickly converted to nitrogen dioxide (NO_2) through oxidation with ozone in the atmosphere such that for the downwind , NO_x may contain about 90% of NO_2 (Oluleye, 2012).

The model takes into account different time scales (1-h, 8-h and 24-h). The aim is to compare the concentrations of each pollutant for different scenarios with standards.

Generally it was observed that the concentrations of the gaseous pollutants are highest at the source point for scenarios using AGO gas and it reduces for the NG fired.

Table 2 shows the scenario designs and the various equipments used intermittently while some are used others are shut down. Scenarios 1 to 3 are similar in the setup due to similar use of natural gas, also Scenario 4 to 6 are also similar due to use of same fuel (AGO).

However, for the purpose of comparing all predicted pollutants concentration with the standards which include FMNEV, EGASPIN, and World Bank Limit. Tables 5 to 10 gives a detailed comparisons of the different scenarios.

The results in Table 5 to 10 show the output of each gaseous pollutant from the AERMOD model for 1-h, 8-h and 24-h respectively.

Table 5 shows the percentage of each pollutant compared to the standard for Scenario 1. In Scenario 1, the fired heaters, atmospheric flare and the gas turbine driven AG compressor are in use in the power plant while the Power Generator Turbine is shutdown. The fuel type used is the natural gas.

The 24-h CO concentration ranges between 0.0001 and 644 $\mu g/m^3$, while for NO_X concentration is between 0.001 and 149.21 $\mu g/m^3$, and the PM_{10} concentration is between 0.00014 and 0.196 $\mu g/m^3$.

The predicted concentrations in CO from the first scenario (scenario 1) for EGASPIN and World Bank Limit are 8.89% for 1-h, 6.40% for 8-h. Also for NO_X, it has a percentage of 9.91%. For 1 and 8 h, FMNEV has no values but 65.48% for 24 h. One hourly average period for NO_X has a maximum concentration of 4163.7 $\mu g/m^3$ and it is 9.91% of EGASPIN which is far below the limit

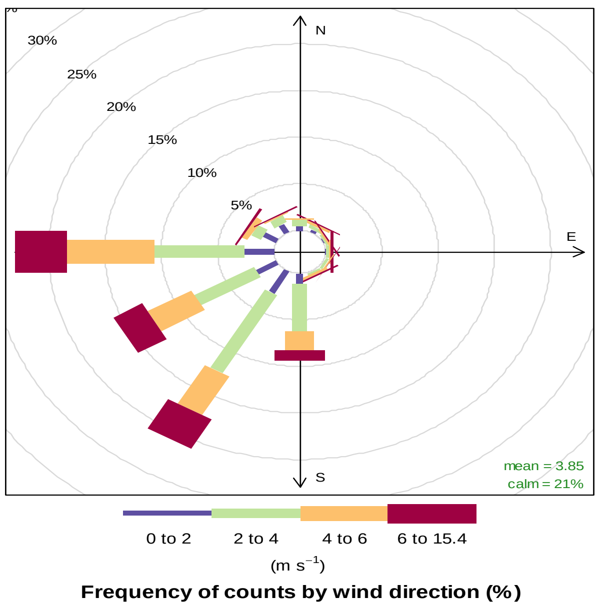

Figure 3. Wind rose of wet season in Omotosho Power Plant.

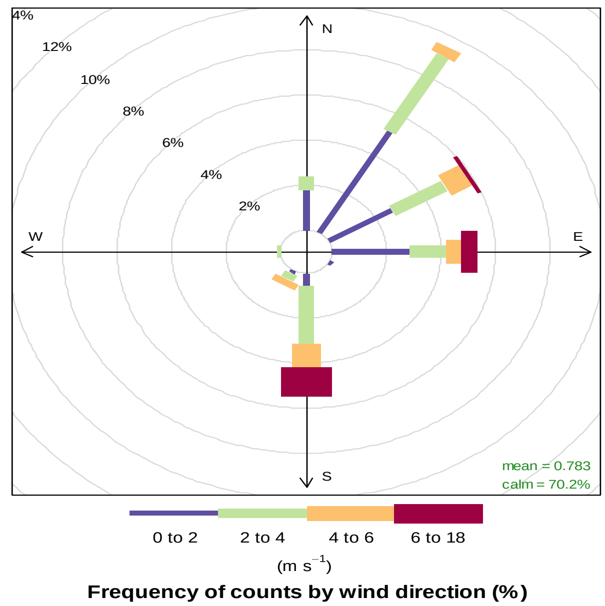

Figure 4. Wind rose of dry season in Omotosho Power Plant.

Table 5. Scenario 1 outputs compared to the standards.

S/No	Pollutants	Average period	Max. Conc. (µg/m^3)	Receptor X	Location Y	Elev. (m)	%*FMENV*	%EGASPIN	%World Bank
		1hr	2664.1	689230	743518	80.4	-	8.89	8.89
1	CO	8hr	2341.5	689002.	744458	88.5	2.82	-	6.40
		24hr	644.1	684420.	744458	89.5	5.66	6.44	-
		1hr	4163.7	689329.1	745039	81.8	-	9.91	-
2	NO_X	8hr	370.8	689122.0	745127	83.1	-	-	-
		24hr	149.2	689230	743518	80.4	65.48	99.47	99.47
		1hr	0.501	689329	745039	81.8	-	-	-
3	PM_{10}	8hr	0.292	689122	745127	85.4	-	-	-
		24hr	0.196	689087.	744930	85.8	-	-	0.25

Table 6. Scenario 2 output compared to the standards.

S/No	Pollutants	Average period (h)	Max. Conc. (µg/m^3)	Receptor X	Location Y	Elev. (m)	%FMENV	%EGASPIN	%World Bank
		1	2373.9	689866.	744478.0	79.8	-	7.91	7.91
1	CO	8	2286.9	689122	745127.4	85.4	7.84	-	22.8
		24	892.2	689208.8	745619.8	83.4	-	8.92	-
		1	406.3	689600	744352	79.9	-	0.97	-
2	NO_X	8	333.9	689122.9	745127	85.4	-	-	-
		24	130.7	689087	745217	85.4	44.6	87.13	87.13
		1	0.10	689230.0	743888	83.1	-	-	-
3	PM_{10}	8	0.66	689152.7	744796.	83.9	-	-	-
		24	0.01	689211.5	74877.7	83.9	-	-	0.01

Table 7. Scenario 3 output compared to the standards.

S/no	Pollutants	Average period (h)	Max. Conc. (μg/m^3)	Receptor X	Location Y	Elev (m)	%FMENV	%EGASPIN	%World Bank
		1	10.07	689052.6	74483.9	85.8	-	0.03	0.03
1	CO	8	7.61	689152.7	744796	82.9	-	-	-
		24	2.82	689093	744796	83.9	0.02	0.03	-
		1	12.48	689211.5	744877	82.9	-	0.03	-
2	NO_X	8	9.31	689152	745444	85.8	-	-	-
		24	2.80	689093.9	744796	83.9	3.11	1.87	1.87
		1	0.71	689087	744930	84.9	-	-	-
3	PM_{10}	8	0.31	688700	744490	91.8	-	-	-
		24	0.13	689211	744877	82.9	-	-	-

Table 8. Scenario 4 output compared to the standards.

S/no	Pollutants	Average period	Max. Conc (μg/m^3)	Receptor X	Location Y	Elev (m)	%FMNEV	%EGASPIN	%World Bank
		1	7319.78	689069.9	744831.9	85.8	-	24.4	24.4
1	CO	8	2580.88	689211	744877.7	82.9	11.3	-	25.8
		24	1659.3	689866.1	744498.1	83.9	14.58	16.59	-
		1	203.81	689152.7	744877	83.9	-	0.49	-
2	NO_X	8	144.3	688842.	745561.0	81.9	-	-	-
		24	29.99	689600	744478.0	79.8	33.26	19.99	19.99
		1	11.10	689152	744796	83.9	-	-	-
3	PM_{10}	8	8.90	689152	744877	82.9	-	-	-
		24	0.43	689208.8	745619	83.4	-	-	-
		1	10.45	689152	744930	83.9	4.02	-	-
4	SO_2	8	4.35	689211	744490	81.8	-	-	-
		24	1.56	689052	744877	85.9	6.03	-	1.95

but for 24 h is 99.47% for EGASPIN and World Bank which is almost exceeding the standards. In Scenario 1 natural gas is in use then the particulate matter may not be a significant emission of the process as shown in scenario 1 to 3.

Table 6 shows the output from Scenario 2 in which the atmospheric flare, gas turbine driven AG compressor, power generator turbine drivers are all in use while the fired heater is shut down. The natural gas is in use.

Scenario 2 has a lower percentage compared to scenario 1.The percentage reduces from 99.47% in Scenario 1 to 87.13% for EGASPIN and FMNEV.

In Scenario 2, the predicted 24-h concentration of CO ranged between 0.00002 and 892.2 μg/m^3 following the same trend as Scenario 1. The 24-h average concentration of NO_X decreases from 406.3 to 130.748 μg/m^3 1 h-concentration. The surface plot of the average concentration of 1-h, 8-h, 24-h concentrations are shown in Figures 5 to 7.

Observation made is that there is a decrease in the average concentration of the pollutants in the Scenario 2 compared to that of Scenario 1. Generally, the predicted ground level concentrations of the various gaseous pollutants are below the FMENV, EGASPIN and the World Bank Limits.

In Table 7, the equipment in use are fired heaters and power generator turbine drivers while all other equipment are shut down. The fuel in use is the Natural gas. Scenario 3 is the best scenario, with low concentrations for all the pollutants. This shows the ideal setup of a processing system for a power plant as this will have a negligible impact on the environment.

Table 9. Scenario 5 output compared to the standards.

S/no	Pollutants	Average period (h)	Max.Conc ($\mu g/m^3$)	Receptor X	Location Y	Elev. (m)	%FMNEV	%EGASPIN	%World Bank
		1	56.8	689152.9	744877	81.8	-	0.19	0.19
1	CO	8	53.88	689600	744352	79.9	0.23	-	0.53
		24	14.04	689152.1	744877	82.9	0.12	0.14	-
		1	1.98	689122	745127	83.9	-	0.005	-
2	NO_X	8	0.7	689622	745561.0	81.9	-	-	-
		24	0.27	689600	744478.0	79.8	0.3	0.18	0.18
		1	0.11	689211	744799	82.9	-	-	-
3	PM_{10}	8	0.03	689152	744367	82.9	-	-	-
		24	0.02	689208.8	745156	79.0	-	-	-
		1	0.02	689152	743930	81.9	0.008	-	-
4	SO_2	8	0.01	689211	744489	82.8	-	-	-
		24	0.01	689052	744467	79.9	0.04	-	0.01

Table 10. Scenario 6 output compared to the standards.

S/no	Pollutants	Average period (h)	Max. Conc. ($\mu g/m^3$)	Receptor X	Location Y	Elev. (m)	%FMNEV	%EGASPIN	%World Bank
		1	7316.8	689342.9	744877	85.8	-	24.39	24.39
1	CO	8	5259.7	689246	744352	83.9	23.1	-	52.5
		24	1412.89	689646.1	744877	82.9	12.2	14.2	-
		1	239.03	689245	745127	84.9	-	0.57	-
2	NO_X	8	77.24	689645	745561.0	82.9	-	-	-
		24	54.99	689245	744478.0	83.8	60.39	36.66	36.66
		1	15.61	689123	744799	79.9	-	-	-
3	PM_{10}	8	10.29	689167	744367	79.9	-	-	-
		24	3.88	689138.8	745156	83.0	-	-	-
		1	4.68	689145.4	743930	82.9	1.8	-	-
4	SO_2	8	4.46	689245	744489	82.8	-	-	-
		24	2.59	689546	744467	83.9	1.97	-	3.23

In Scenario 3, CO concentration is 0.03% and 0.03% of EGASPIN and World Bank Limit while for 24 h is 0.02%. For NO_X, 1hr concentration is 0.03% of EGASPIN and 24 h concentration is 3.11% of FMNEV and 1.87% of both EGASPIN and World Bank.

Due to the abundance of naturally occurring nitrogen in the atmosphere, operating conditions play significant role in NO_X formation in combustion activities, predicted 24-h maximum concentrations from Table 6 indicate a range of 0.0002 to 2.8 $\mu g/m^3$.

Table 8 shows the outputs compared to standards for Scenario 4, similar to Scenario 1 but the AGO fuel also known as diesel is in use. In Scenarios 4 and 5, the CO is 24.4 and 0.19% respectively and the 24 h is 14.58 and 0.12% of FMNEV and 16.59 and 0.14% of EGASPIN. For $NO_{X,}$ 0.49% of EGASPIN and for 24 h has a concentration of 33.26% of FMNEV, 19.99% of EGASPIN and World Bank. SO_2 has a concentration of 4.02% for 1 h and 6.0% for 24 h.

The predicted maximum concentration for CO in this scenario for 1 h is the highest as we have 7316.8 $\mu g/m^3$ at an elevation of 85.8 m and decreases to 5259.7 $\mu g/m^3$

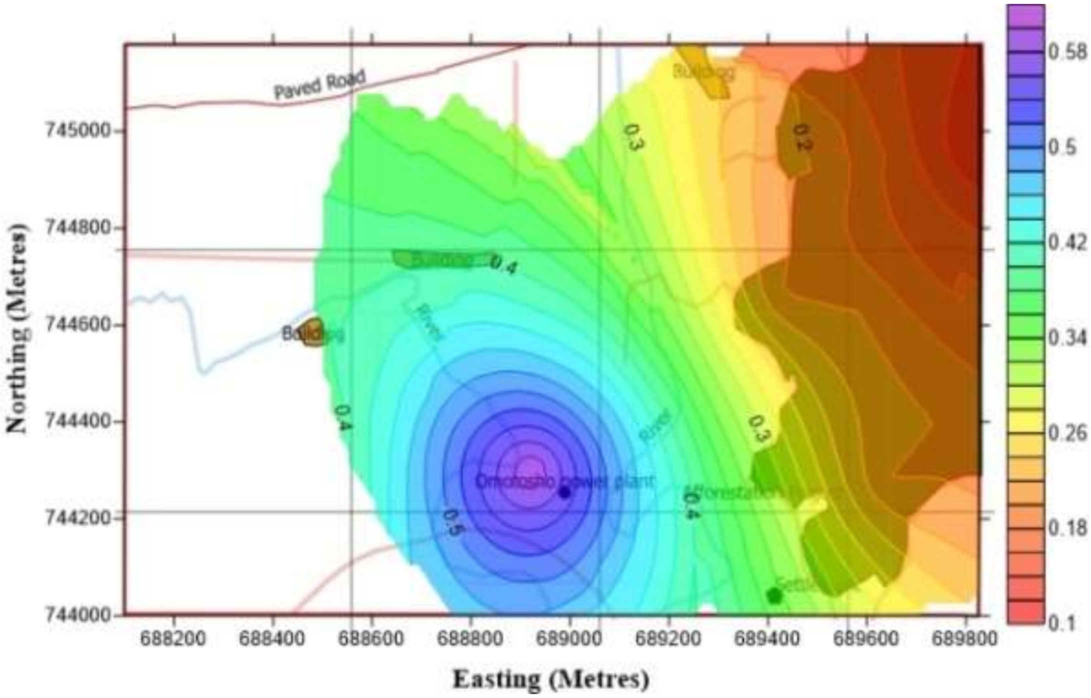

Figure 5a. One–hour average concentration of CO for Scenario 1 (contours in multiples of 10000).

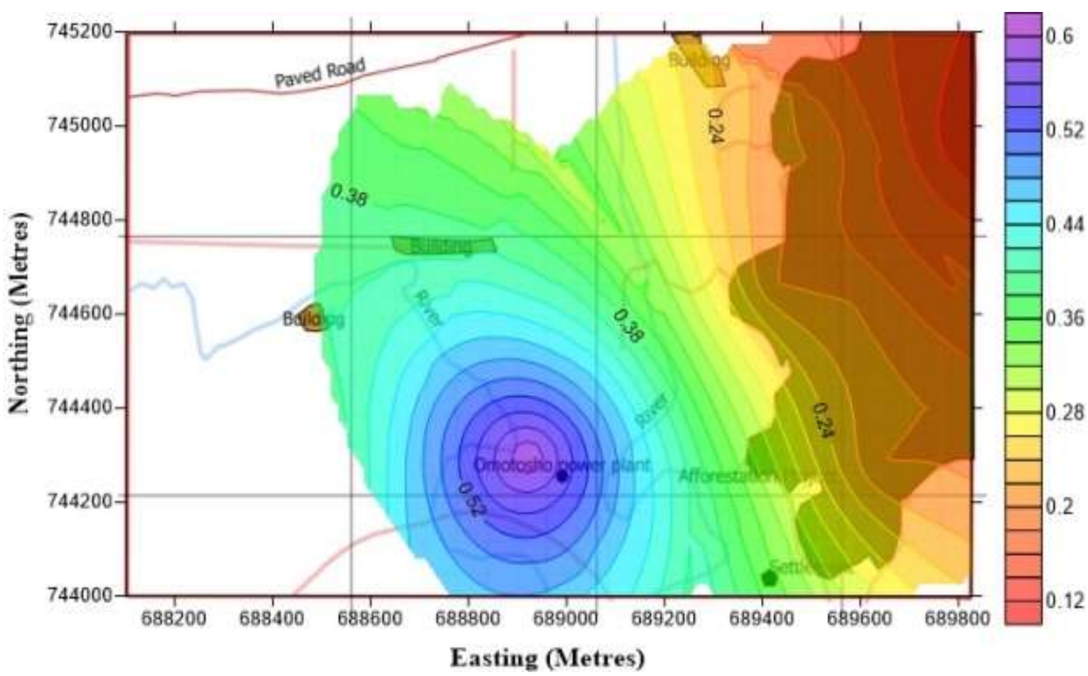

Figure 5b. One–hour average concentration of CO for Scenario 2 (contours in multiples of 10000).

in 3-h and then decreases to 1659.3 $\mu g/m^3$ for 24 h at 79.82 m. This shows that the concentration is highest at the top elevation and as the pollutant disperses downward it has little concentration thereby having less effect on airshed.

As earlier said, the worst case scenario is scenario 4 with AGO-fired facilities as represented in Table 9 which indicates that the predicted ground level of CO is very high followed by NO_X followed by PM_{10} and then SO_2.

Scenario 5 has a low concentrations compared to

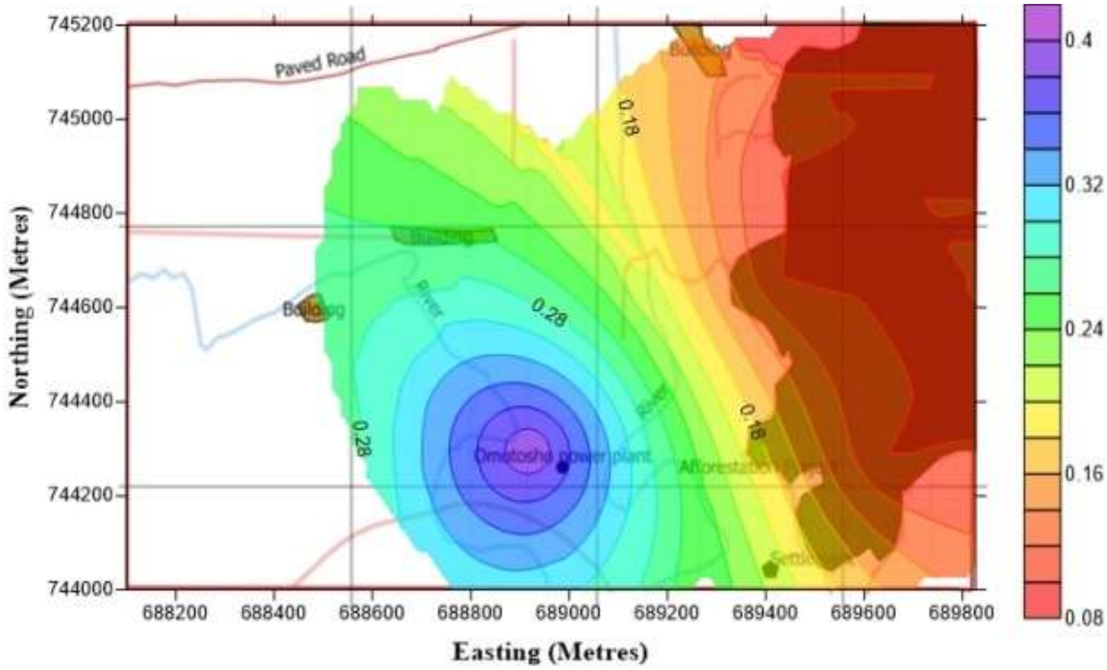

Figure 5c. One–hour average concentration of CO for Scenario 3 (contours in multiples of 10000).

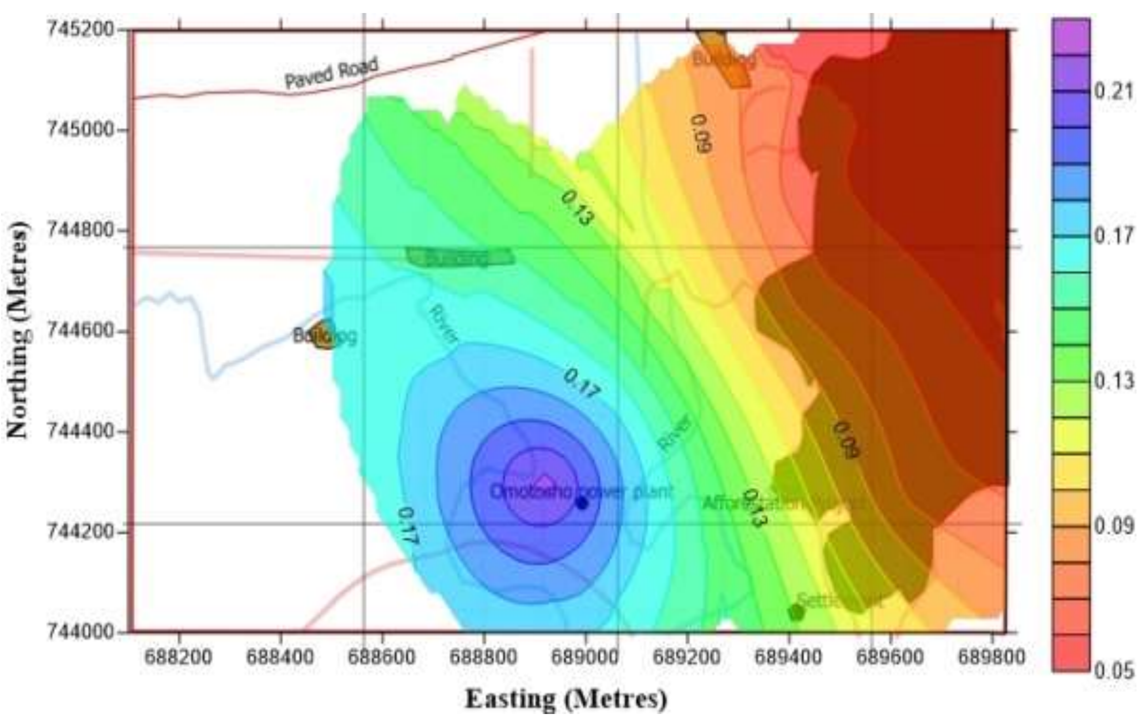

Figure 5d. One–hour average concentration of CO for Scenario 4 (contours in multiples of 10).

scenario 4 and also the ground level concentration of the pollutants being compared with the standard limit is very low. For CO, the 1-h average concentrations is 56.8 $\mu g/m^3$ which reduces to 53.8 $\mu g/m^3$ for 8-h and then reduces to 14.04 $\mu g/m^3$. It is observed that in the entire scenario (scenario 1 to scenario 6), CO always has the highest concentration. For NO_X, the 1-h concentration is 1.98 $\mu g/m^3$ and reduces to 0.7 $\mu g/m^3$ for 1-h and then to 0.28 $\mu g/m^3$ for 24-h.

Scenario 5 concentrations are very low because the

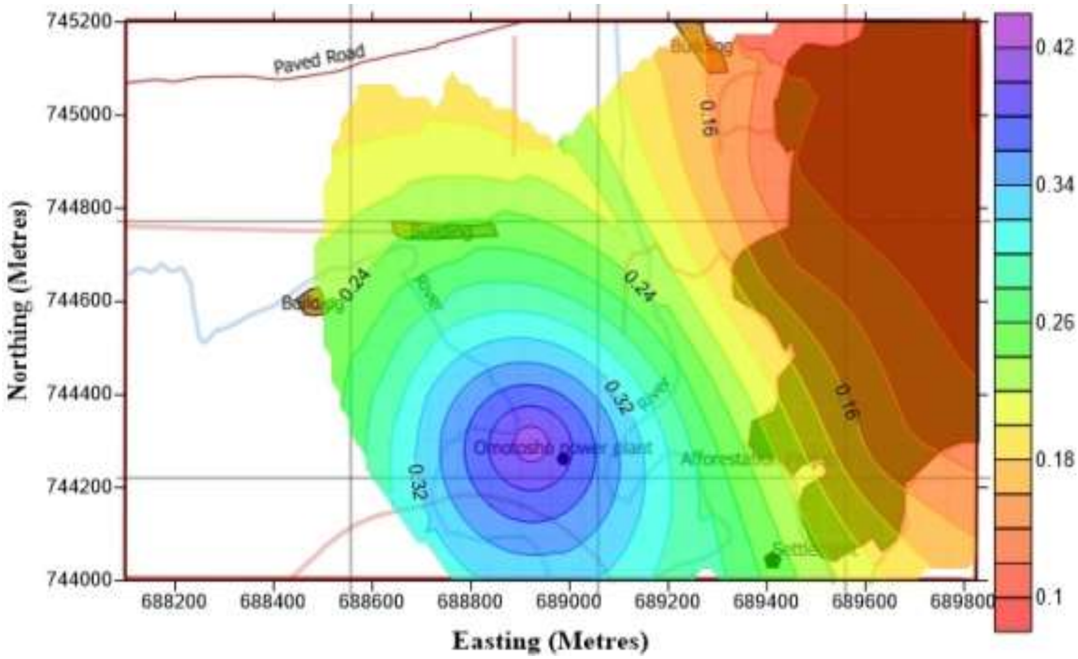

Figure 5e. One-hour average concentration of CO for Scenario 5 (contours in multiples of 10).

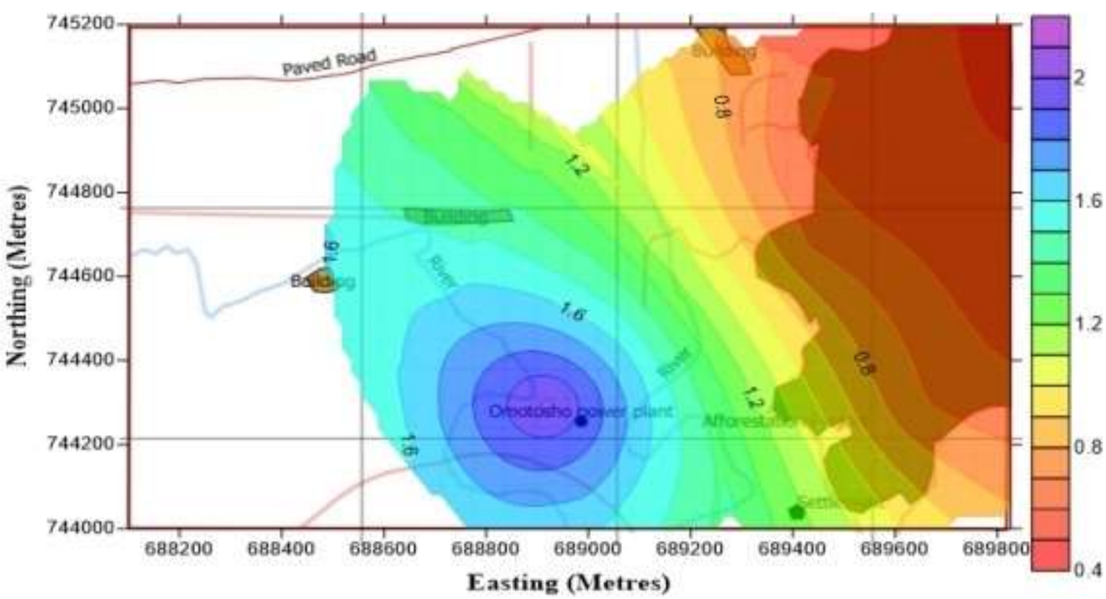

Figure 5f. One-hour average concentration of CO for Scenario 6 (contours in multiples of 100).

Figure 5(a-f). AERMOD estimated surface concentration of CO in Omotosho Power Plant.

atmospheric flare is not contributing to the emission due to zero fuel consumption (kg\h) as shown in Table 9. The various pollutants in this scenario are very low compared to Scenario 4 and Scenario 6.

Also as a result of the low concentration, it will be much than the various guidelines limit including % World Bank. As long as the concentrations of the various pollutants do not exceed the standard the environment and the ecosystem is safe. In Scenario 5, the fuel used is the AGO fired fuel very similar to that of Scenario 2 which uses NG fired fuel.

Scenario 6 and Scenario 4 are very similar with high concentration compared to the other scenarios. But Scenario 4 is higher because its use just involves three

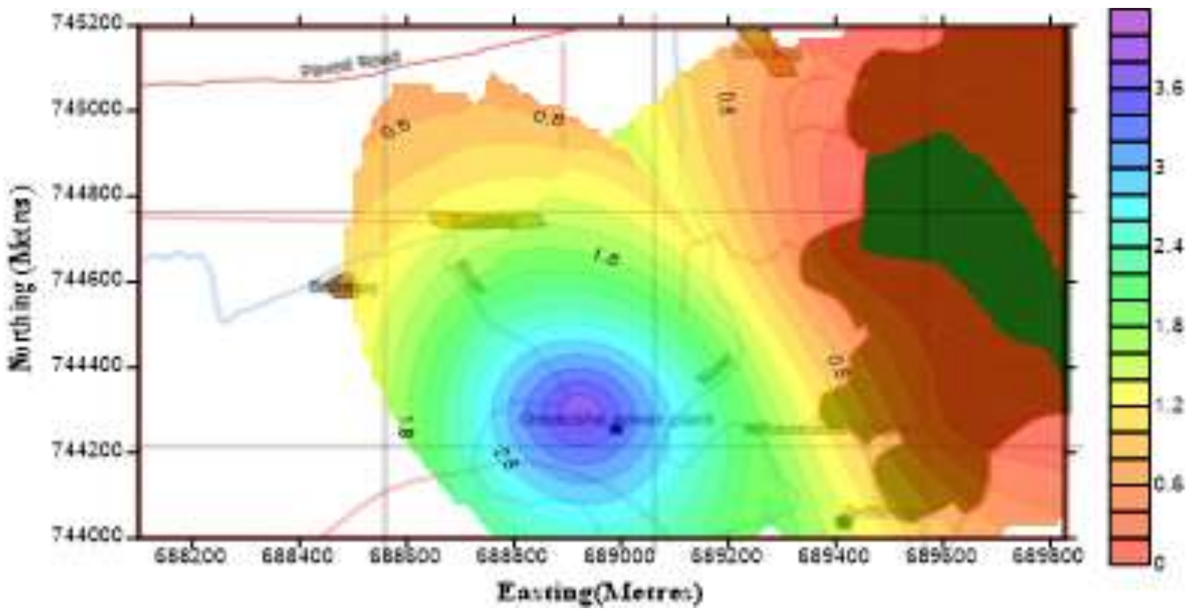

Figure 6a. Eight-hour average concentration of NO_X for Scenario 1 (contours in multiples of 1000).

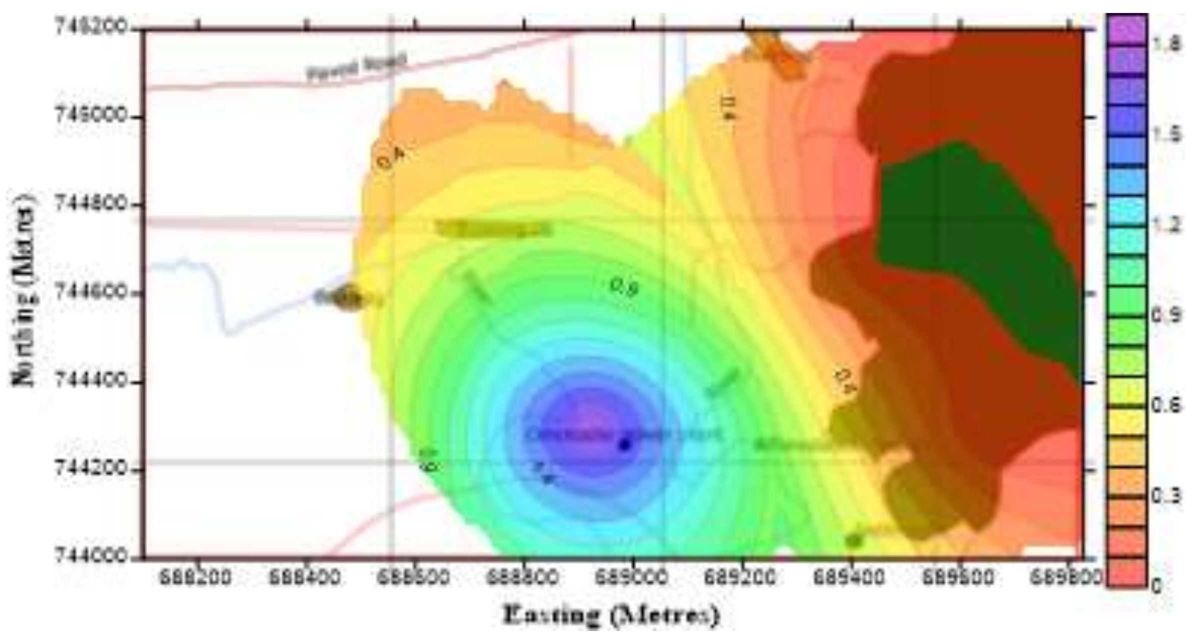

Figure 6b. Eight-hour average concentration of NO_X for Scenario 2 (contours in multiples of 1000).

equipment which is the fired heater, atmospheric flare and gas turbine derived AG compressors unlike scenario 6 that uses two equipment of fired heaters and power generators. Scenario 6 has 24.39% for both EGASPIN and World Bank Limit. In scenario 6, maximum concentration for 1 h are 7316.8, 239.03, 15.618 and 4.68 $\mu g/m^3$ for CO, NO_X, PM_{10} and SO_2, respectively. Similar trend of concentration occurred for 8 and 24 h.

Scenario 6 and scenario 4 are the two worst scenarios. Maximum modeled 24-h concentrations for all the scenarios are 1659.3 $\mu g/m^3$. The elevation height for simulation of concentration ranges between 60metres and 100metres in Omotosho Power Plant. The pollutants emitted in the greatest concentration in their order of magnitude were CO, NO_X, PM_{10} and SO_2.

Summarily, the scenarios show the same increase of concentration for 1-h, 8-h and 24-h. It is also observed that Scenario 3 and Scenario 5 have lowest concentration compared to Scenario 1, Scenario 2 and Scenario 6. The former scenarios use natural gas fuel;

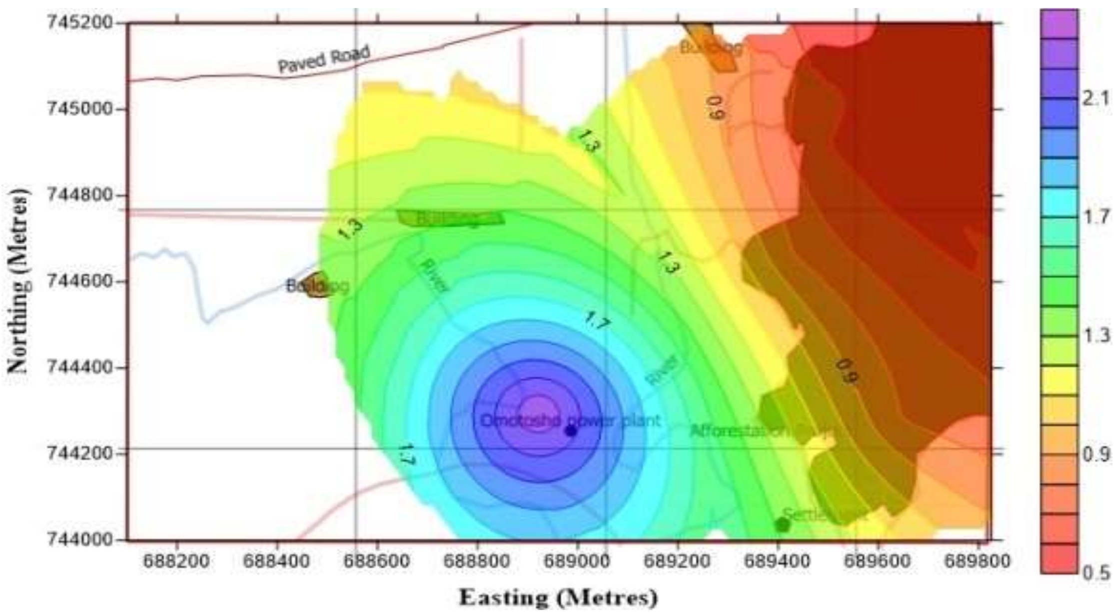

Figure 6c. Eight -hour average concentration of NO_X for Scenario 3 (contours in multiples of 10000).

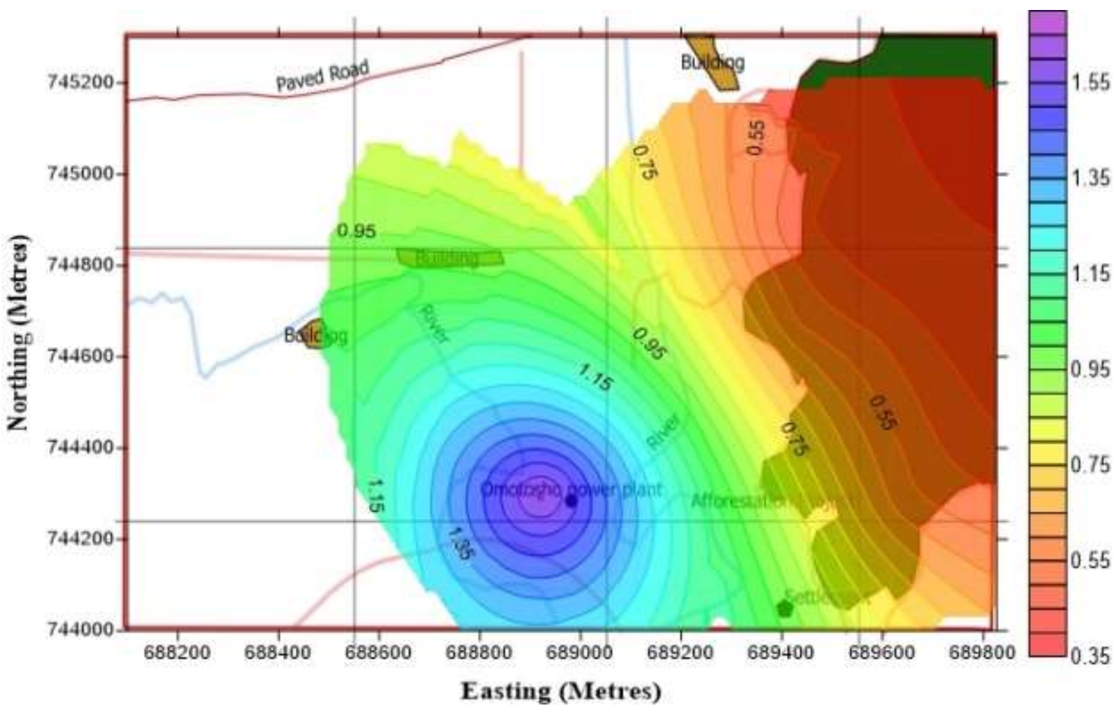

Figure 6d. Eight -hour average concentration of NO_X for Scenario 4 (contours in multiples of 1000).

Scenario 5 uses AGO fired fuel. In Scenario 3, it is observed that the concentration is low as a result of the use of NG fired fuel which has a low input of fuel discharges this justifies the research as the output shows that the natural gas fired fuel has a low concentration of pollutant than AGO fired.

Scenario 6 is the next worst scenario to Scenario 4, the FMENV, EGASPIN and World Bank limit were almost exceeded. Several contributing factor causes the high concentration of these pollutants; the fuel used, the equipment for the scenarios. In scenarios 4 to 6, there is an addition pollutant expected in the form of SO_2 which is absent in scenario 1 to scenario 3 due to the sweetness of natural gas of Nigeria origin.

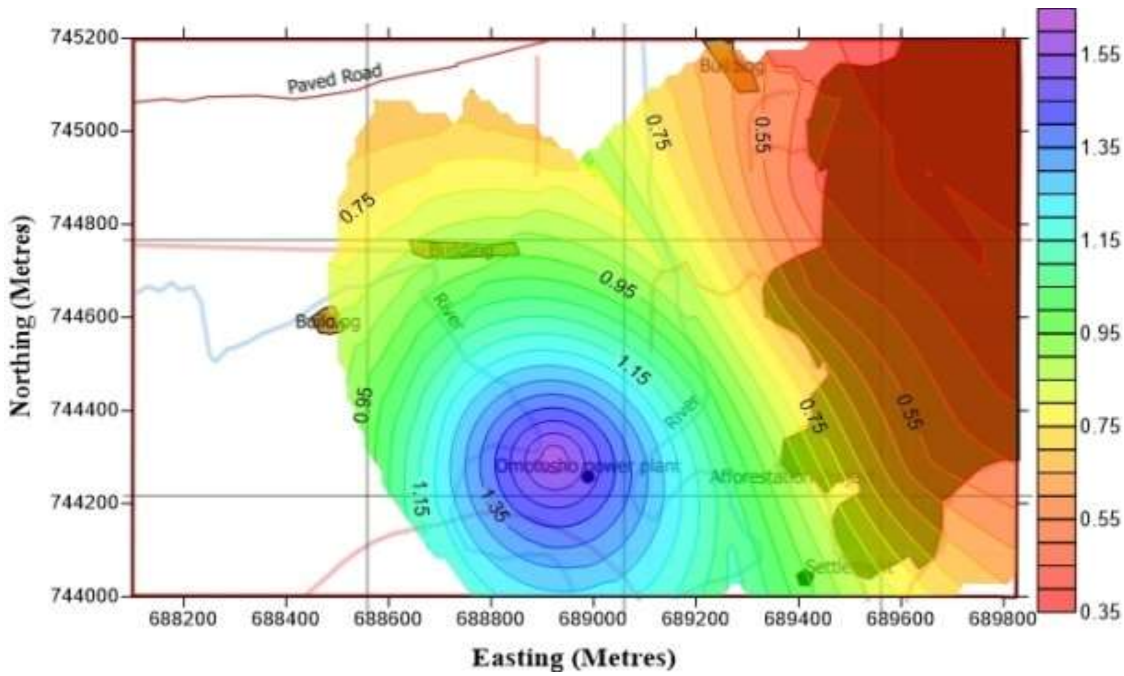

Figure 6e. Eight-hour average concentration of NO_X for Scenario 5 (contours in multiples of 1000).

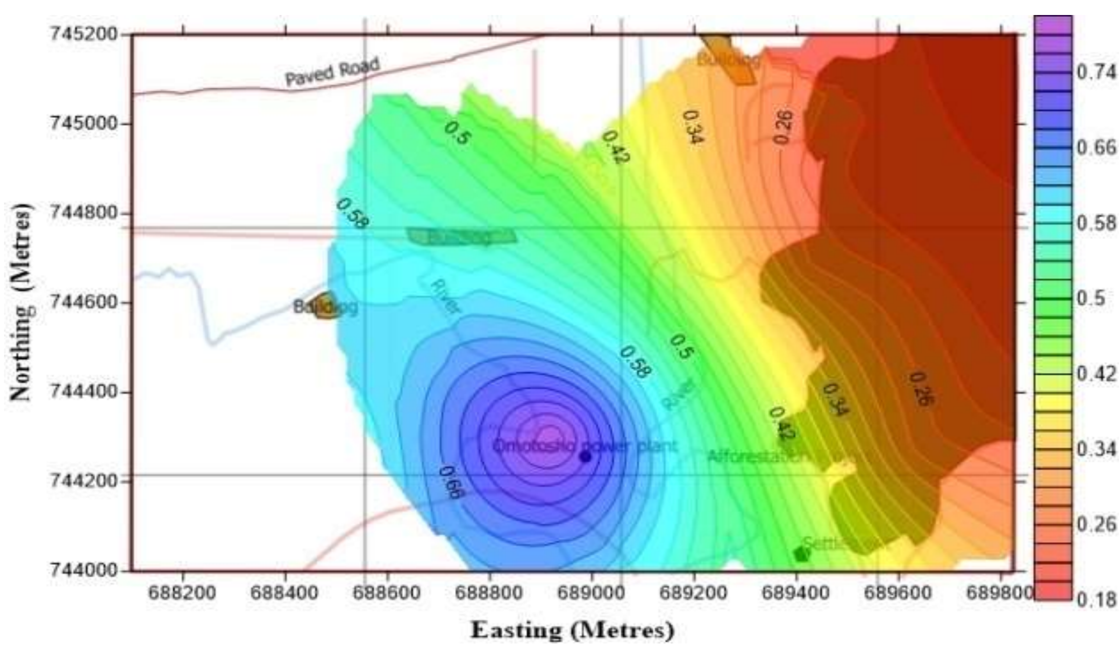

Figure 6f. Eight-hour average concentration of NO_X for Scenario 6 (contours in multiples of 1000).

Figure 6(a-f). AERMOD estimated surface concentration of NO_X in Omotosho Power Plant.

CO plots for scenario 1 to 6

Figure 5(a-f) AERMOD estimated surface concentration of CO in Omotosho Power Plant. The contour plots for CO concentration in Figure 5(a-e) are shown. Scenario 1 CO concentrations range from 0.1 to 0.58 μg/m^3, Scenario 2 concentration between 0.12 and 0.60 μg/m^3. Scenario 3 concentration ranges from 0.08 to 0.40 μg/m^3, Scenario 4 concentration ranges from 0.05 to 0.21 μg/m^3, Scenario 5 ranges from 0.1 to 0.42 μg/m^3 and Scenario 6 ranges from 0.4 to 2.0 μg/m^3. CO concentrations are maximum in all the scenarios, the power plant has the

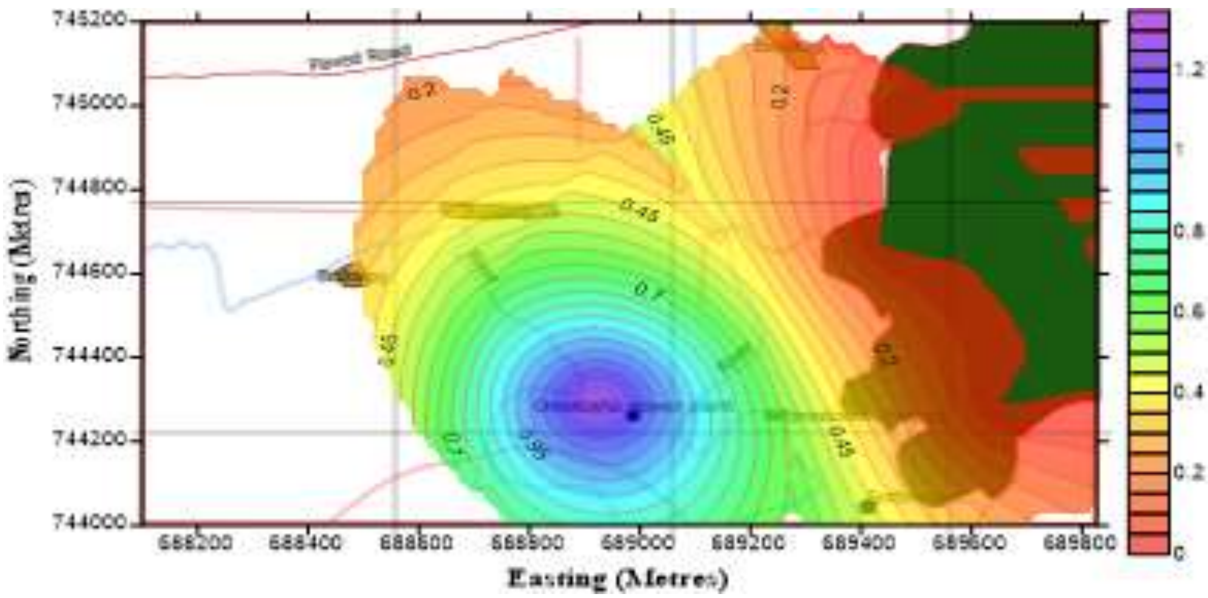

Figure 7a. Twenty four-hour average concentration of PM_{10} for Scenario 1 (contours in multiples of 1000).

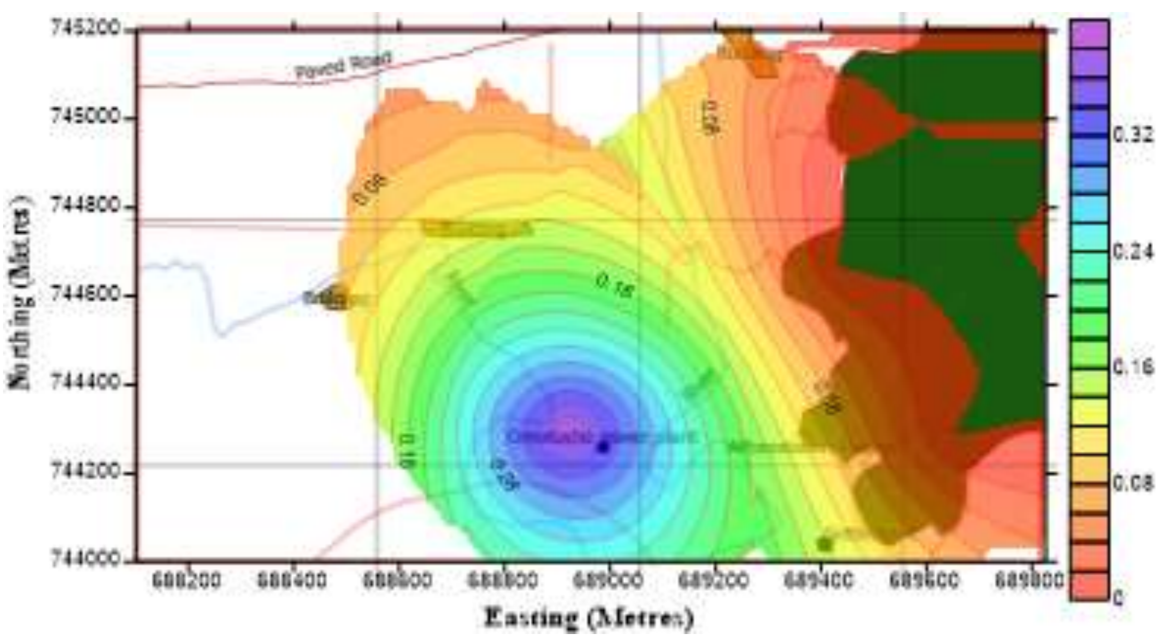

Figure 7b. Twenty four-hour average concentration of PM_{10} for Scenario 2 (contours in multiples of 1000).

highest concentration at the source compared to the receptors and all the processing system is from that location. As it is also shown the predominant wind is southwesterly therefore the gaseous pollutants emitted are blown away from the direction to have reduced concentration overtime.

NO_X plots for scenarios 1 to 6

The contour plots for the pollutants are shown in Figure 6(a-f). For scenario 1 the concentrations ranges from 0.0 to 3.8 μg/m^3, 0.0 to 1.80 μg/m^3, 0.5 to 2.2 μg/m^3, 0.5 to 0.21 μg/m^3, 0.35 to 1.55 μg/m^3 and 0.18 to 0.74 μg/m^3 for scenarios 1, 2, 3, 4, 5 and 6, respectively.

PM_{10} plots for scenario 1 to scenario 6

Figure 7(a to f) shows the plot for all the scenarios, PM_{10} concentration ranges from 0.0 to 1.40 μg/m^3, 0.0 to 0.38 μg/m^3, 0.0 to 0.38 μg/m^3, 0.0 to 0.38 μg/m^3, 0.0 to 0.38

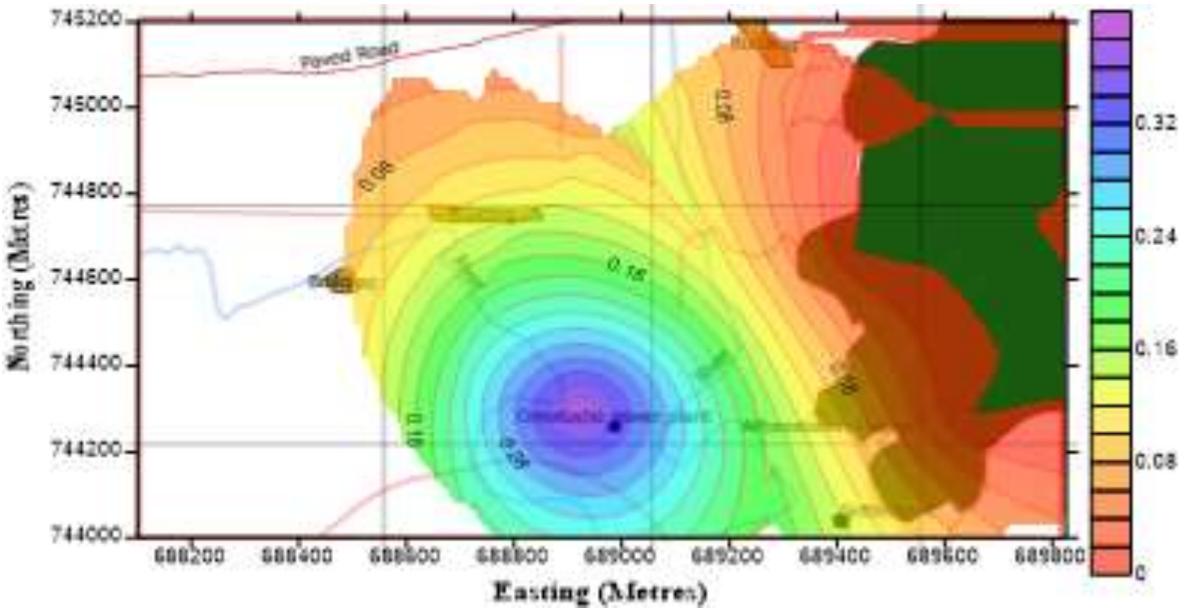

Figure 7c. Twenty four - hour average concentration of PM_{10} for Scenario 3 (contours in multiples of 100).

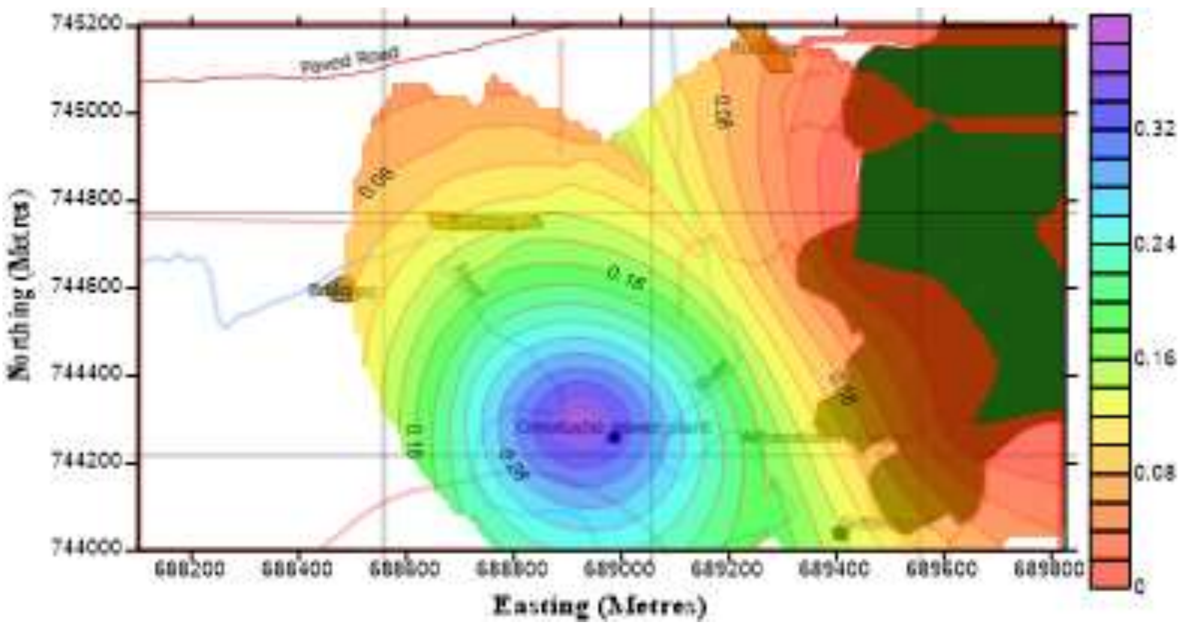

Figure 7d. Twenty four-hour average concentration of PM_{10} for Scenario 4 (contours in multiples of 1000).

$\mu g/m^3$ and 0.0 to 0.24 $\mu g/m^3$ for scenarios 1, 2, 3, 4, 5 and 6, respectively.

SO_2 plots for scenario 4 to 6

Figure 8(a-c) shows the contour lines of SO_2, Scenario 4 ranges between 0.95 and 1.95 $\mu g/m^3$, Scenario 5 ranges between 0.08 and 0.4 $\mu g/m^3$ and Scenario 6 ranges between 0.095 and 0.195 $\mu g/m^3$.

SO_2 plots for scenario 4 to scenario 6

Figure 9(a-c) shows the contour lines of SO_2, Scenario 4 ranges between 0.0 and 1.4 $\mu g/m^3$, Scenario 5 ranges between 0.0 to 0.42 $\mu g/m^3$ and Scenario 6 ranges between 0.0 and 0.0 $\mu g/m^3$.

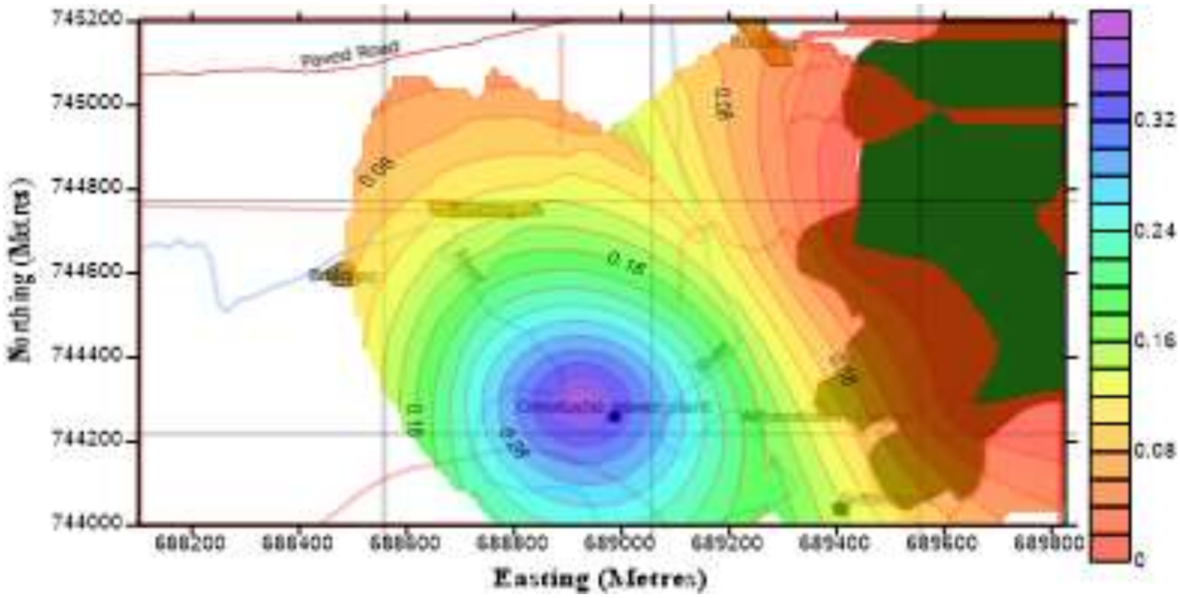

Figure 7e. Twenty four -hour average concentration of PM_{10} for Scenario 5 (contours in multiples of 10).

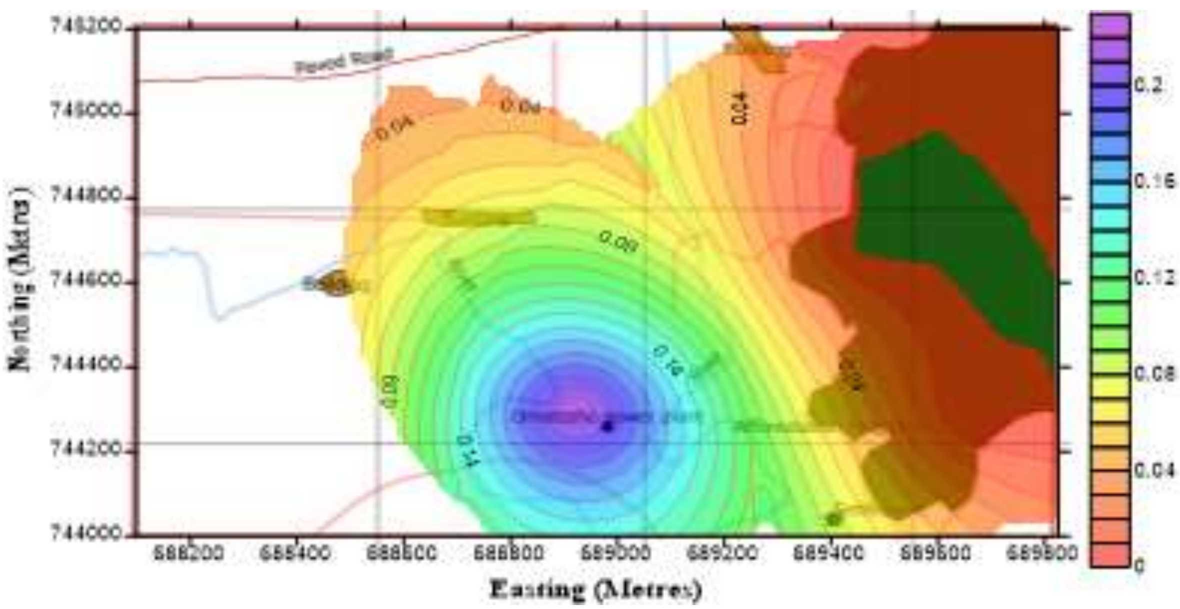

Figure 7f. Twenty four -hour average concentration of PM_{10} for Scenario 6 (contours in multiples of 100).

Figure 7(a-f). AERMOD estimated surface concentration of PM_{10} in Omotosho Power Plant.

Air dispersion model results

The spread of emissions is affected by climatic conditions which determine their deposition rates that influence ground level concentrations. In the plume many organic pollutants experience varying degrees of "hoping" during their environmental journey and consequently become fractionated with distance from the source (Gouin et al., 2004). There is also the possibility of both diffusion and advection away from the source, thus creating environmental problems in their surroundings (Sonibare et al., 2007).

Concentration distribution of air pollutants

The average concentration distributions of the various gaseous pollutants are plotted on the map of the study

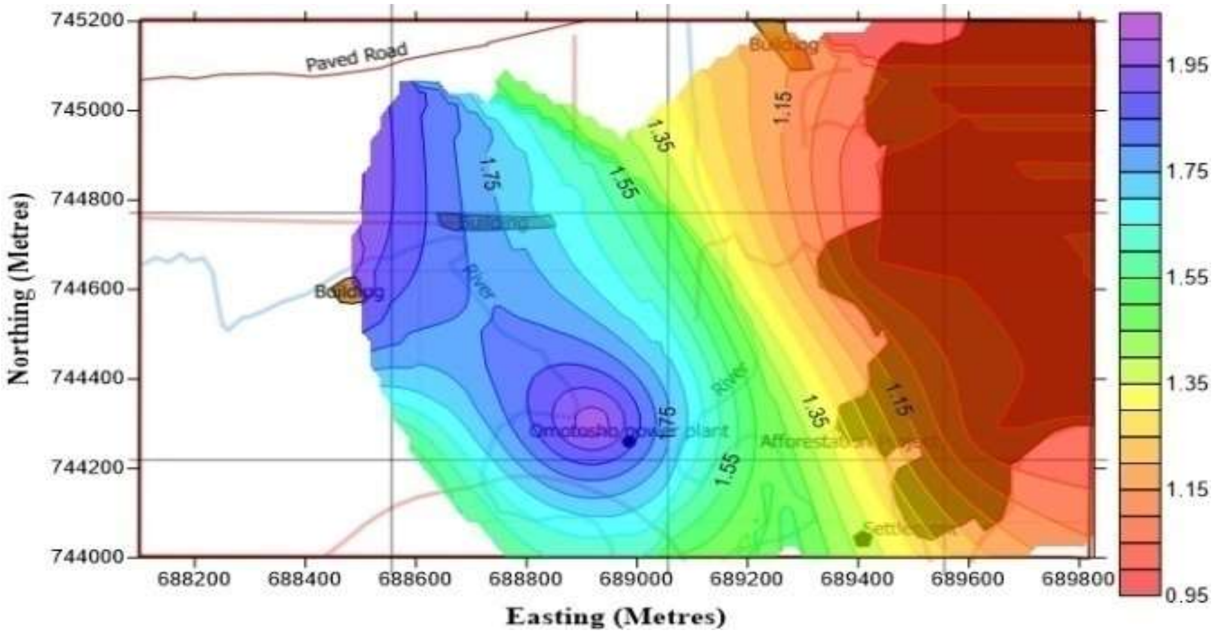

Figure 8a. One-hour average concentration of SO_2 for Scenario 4 (contours in multiples of 100000).

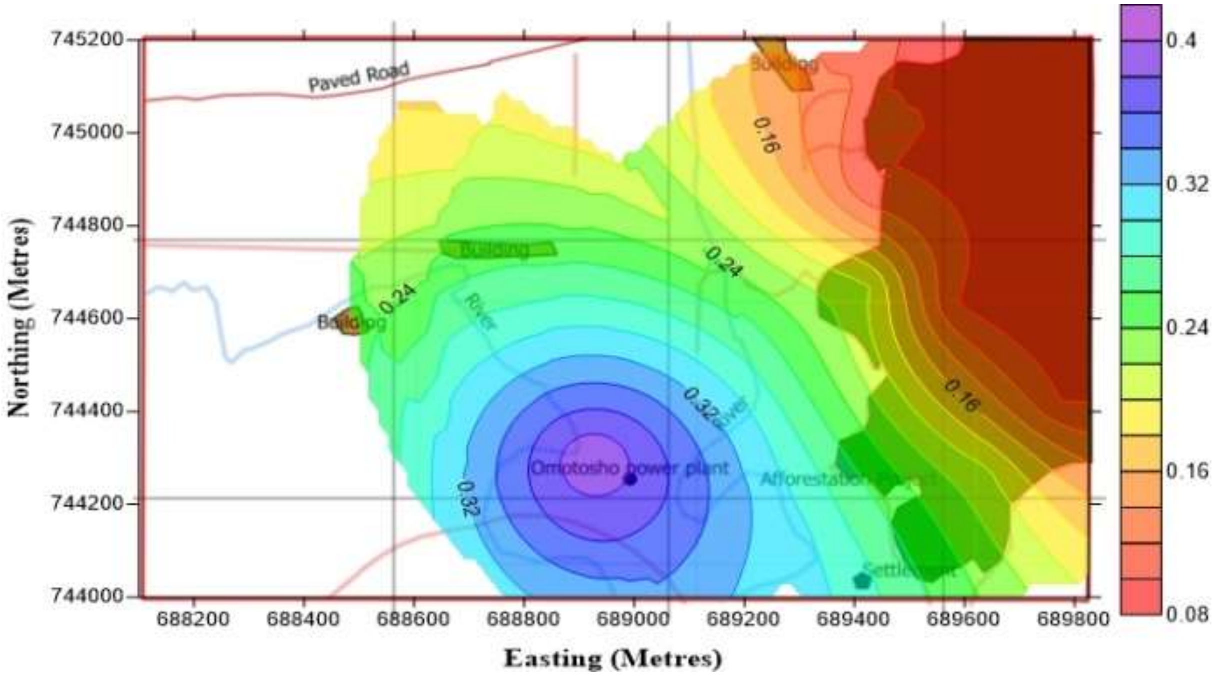

Figure 8b. One-hour average concentration of SO_2 for Scenario 5 (contours in multiples of 10000).

area.

Receptor and sources

The significance of the predicted impacts is assessed using the criteria set out in the six different scenarios. The analyses are based upon the maximum predicted impact for any of the two years of meteorological data. The results of the air dispersion modeling assessment for the receptors and sources indicate a negligible impact significance rating for all the average concentration in the scenarios; the exceptions to this are discussed below by the potential gaseous pollutant of interest. e.g CO, NO_X,

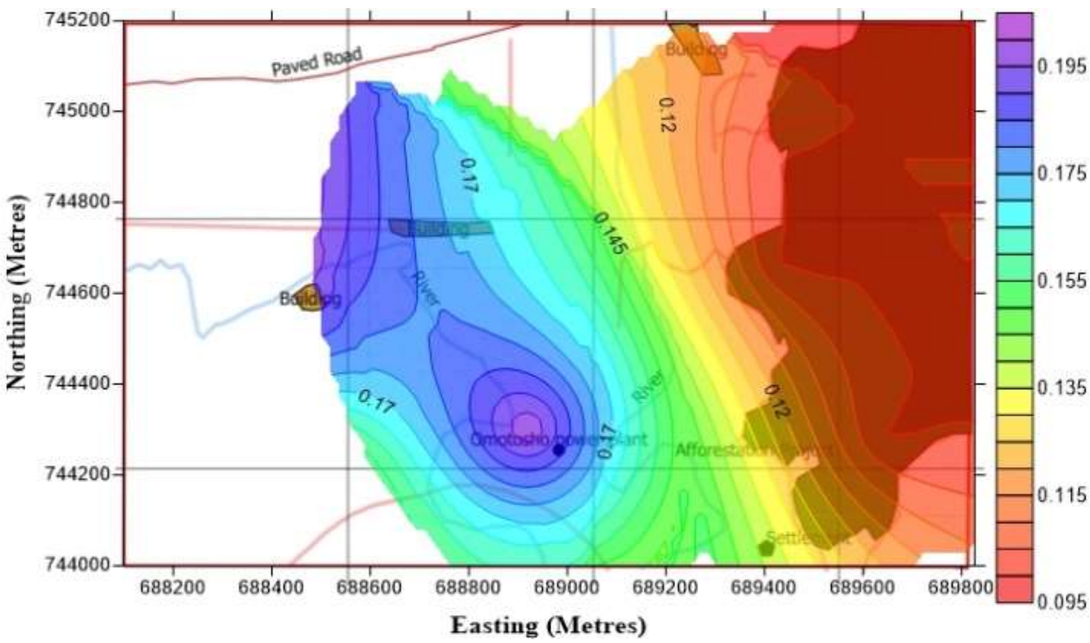

Figure 8c. One-hour average concentration of SO_2 for Scenario 6 (contours in multiples of 10000).

Figure 8(a-c). AERMOD estimated surface concentration of SO_2 in Omotosho Power Plant.

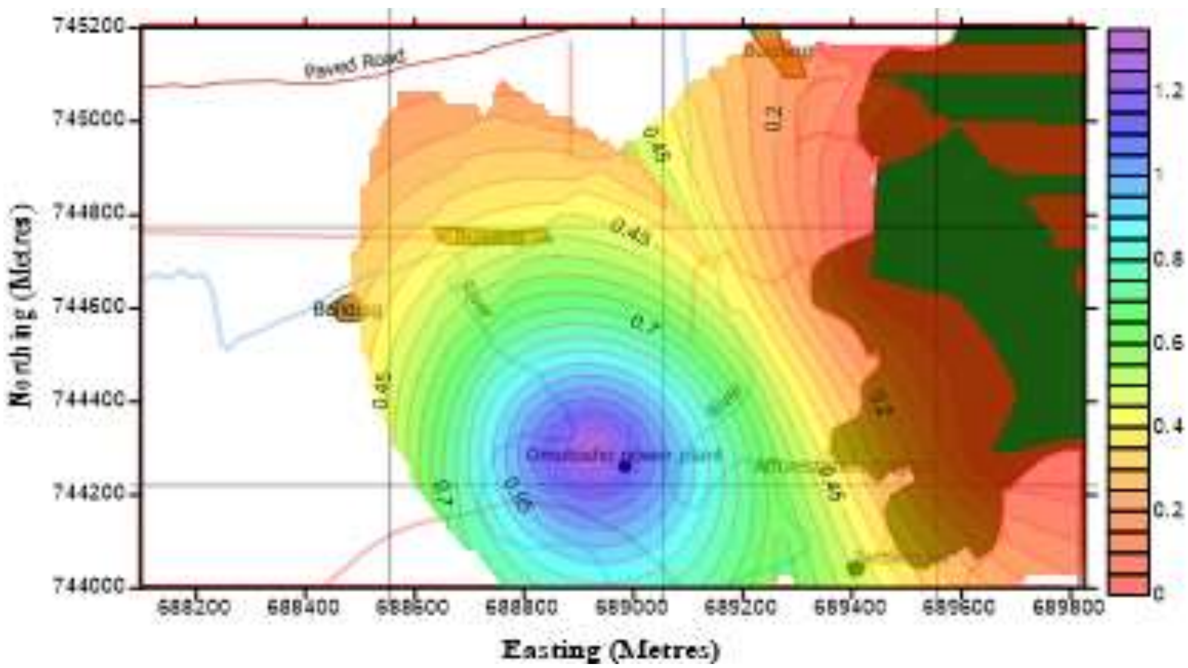

Figure 9a. Twenty four-hour average concentration of SO_2 for Scenario 4 (contours in multiples of 1000).

PM_{10}, SO_2.

CO

The results of the dispersion modeling show that CO concentrations vary from scenario to scenario. Scenario 5 has the average concentration (1.0 to 4.2 µg/m³) at the source point observing the scenarios, followed by Scenario 4 (0.5 to 2.1 µg/m³), Scenario 4 to 6 have the highest concentration (using AGO fuel) compared to Scenarios 1 to 3 (using natural gas), the wind blows the

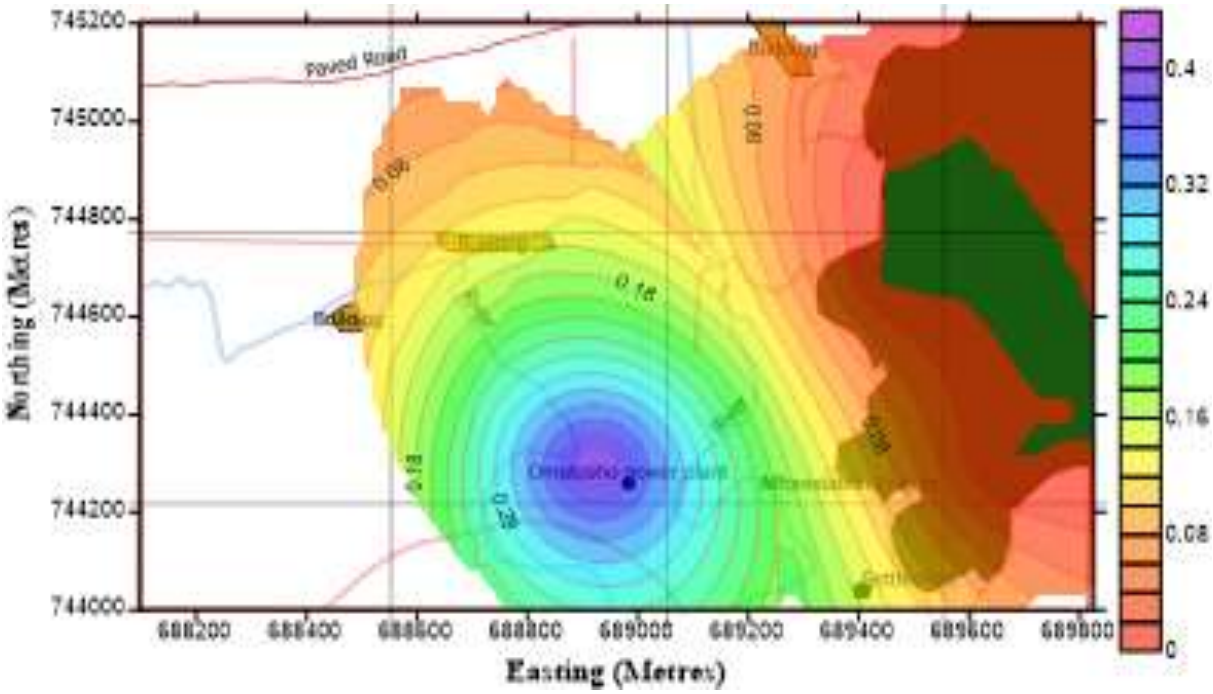

Figure 9b. Twenty four-hour average concentration of SO_2 for Scenario 5 (contours in multiples of 10000).

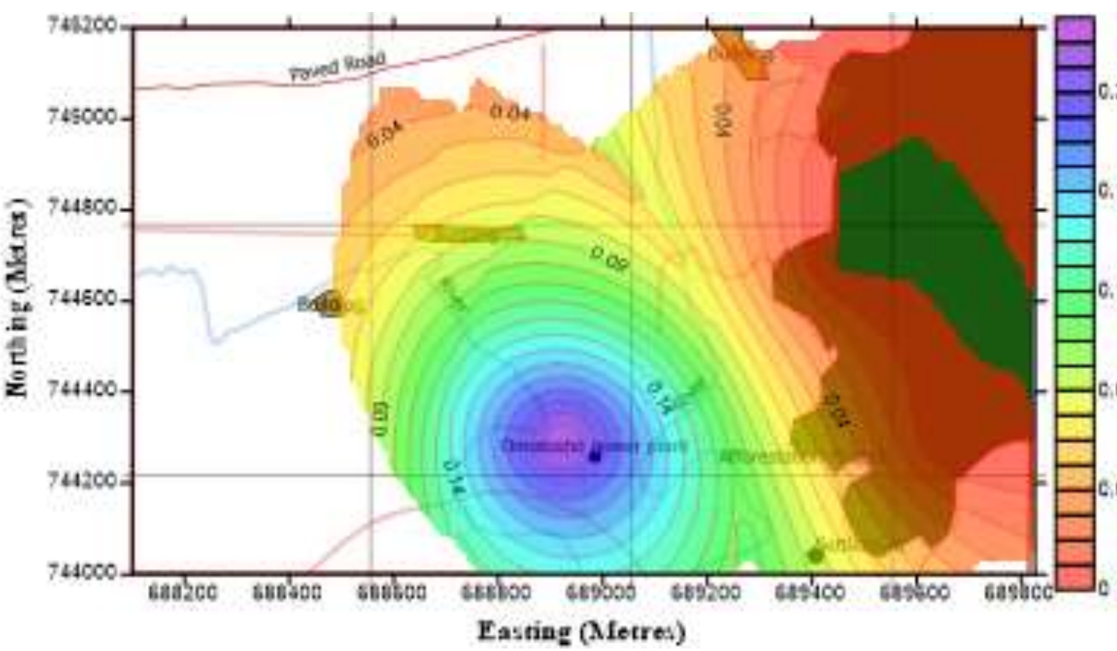

Figure 9c. Twenty four -hour average concentration of SO_2 for Scenario 6 (contours in multiples of 1000).

Figure 9(a-c). AERMOD estimated surface concentration of SO_2 in Omotosho Power Plant.

emission from the source point concentration decreases as it moves far away to the north easterly direction. Scenario 3 has the least or minimal concentration at the source point (0.08 to 0.4 µg/m³) has it uses natural gas fuel. Figure 5a-f shows the concentration of CO.

NO_X

The results of the dispersion modeling show that NO_X concentrations are moderate within Omotosho Power Plant. Oxides of Nitrogen (NO_X) combines Nitrogen oxide(NO) and Nitrogen dioxide (NO_2) although NO is produced from the stack , quick transformation of greater percentage of NO to NO_2 in the presence of sunlight makes it important to treat the oxides as NO_X (Sandanaga et al., 2003). Nitrogen oxides are of concern because of their direct effects and because they are precursors for the formation of ground-level ozone.

Air quality within the confines of the Omotosho Power Plant presents a potential occupational health and safety concern for the environment, but does not present a potential impact to community health. However, in this sixth scenario, modeling result the maximum concentration of NO_X is high in scenarios 1 and 6 but it is still below the guideline limit. Therefore, the impact significance has been assessed as negligible for all the scenarios. This concentration is between 1 and 100 percent of the EGASPIN, FMNEV and World Bank Limit associated with the six modeled scenarios.

Figure 6a-f shows the extent and concentration of NO_X in the modeled scenario and also Table 5 for scenario 1 shows that NO_X limit was almost exceeded.

SO_2

Similar to NO_X, the results of the dispersion model demonstrate that SO_2 concentrations will be highest within the Power Plant for Scenario 6 (1.95 μg/m³) due to the use of AGO fired fuel, but below EGASPIN, FMNEV and World Bank Limits. The impact to community health is expected to be of major impact significance in the majority of circumstances. SO_2 and CO have the highest concentrations because of high emission from the stack. The results of the air dispersion modeling assessment for sensitive ecological receptors indicate the studied emissions will be of major impact significance for all scenarios modeled. For one hourly concentration, it ranges from 1.951 to 0.95 μg/m³, 0.41 to 0.08 μg/m³, 0.195 to 0.095 μg/m³ for scenarios 1, 2 and 3 respectively.

SO_2 has the maximum concentration in scenario 4, for 1 h (10.45 μg/m³), for 8 h (4.35 μg/m³) and 24 h (1.56 μg/m³) emissions from Omotosho Facility.

PM_{10}

The results of the dispersion modeling demonstrate the impacts for PM_{10} in the environment. For all the scenarios, the pollutant has been removed and diffused before getting to the receptor sources because when a pollutant is emitted into the air, it is transported and diluted by the atmosphere and may be transformed or removed before it reaches a receptor (site). For Scenario 1 the average concentration at the source point is 1250 μg/m³ and reduces to zero, concentrations in Scenario 2, 3, 4 and 5 are similar unlike Scenario 6 gives a more negligible impact on the environment compared to the other scenarios (190 μg/m³to a zero). Of all the predicted concentration PM_{10} has the lowest concentration because of low emission from the stack. Figure 7(a-f) shows the extent and concentration of NO_X in the modeled scenario.

CONCLUSION

Wind rose analysis showed that the prevailing wind direction in the modeling domains was from the SW (range 180° to 265°). It is also found that ideal location based on dispersion of pollutants must be non-coastal where high temperature; high wind velocity, surrounding vegetation and lower humidity facilitate the dispersion. The other important governing parameters, as utilities (water, power, storage, piping, export, import) forced the present location as the best.

Air pollution modeling is very essential and important to know the ground level concentration of most pollutants and to assess its impact on airshed. In this study, modeling of pollutants from Omotosho Power Plant and its impact on surrounding environs was assessed.

The model that was used for assessment is the AERMOD model, the AERMOD was ensured that it is very suitable for assessment and it measures up to the necessary requirement. The scenarios with higher concentrations for all the gaseous pollutants are scenario 4 and scenario 6 and this is because of the use of AGO fuel.

The conclusion of this project is that the gaseous pollutants CO, NO_X, PM_{10} and SO_2 did not exceed the regulatory bodies of EGASPIN, FMNEV and World Bank limit. Therefore there is no harmful impact on airshed and surrounding environment. The facility's emission is below standard limits and guideline when compared with appropriate emission limit of EGASPIN, FMNEV and World Bank.

RECOMMENDATION

This research work recommends the use of natural gas fuel in our power plants because of its lower emission compared to the use of AGO fuel which has higher emission and has higher impact on the environment. In addition pollutants from Omotosho Power Plant are below the standard level. Scenarios 1, 2 and 3 should be adopted for our power plants, this is as a result of the equipment used and the fuel.

REFERENCES

Abdelrasoul A.W., Al-Hadad A., Khan A.R. (**2010**). Oil refineries impact on urban localities using AERMOD. Am J Environ Sci, 6(6): 505-515.

Bello N. J. (**2013**). Introduction to Climatology and Biogeography. p 236.

Cimorelli A. J., Perry S. G., Venkatram A., Weil J. C., Paine R. J., Wilson R. B., Lee R. F., Peters W. D., Paumier J. O. (**2003**). AERMOD: description of model formulation. U.S. Environmental

Protection Agency Report, EPA 454/R-03-002d, North Carolina, 85 pages.

Ding F. (**2012**). Analysis of upper air environmental impact of pollutants discharged by power plant. Proc Environ Sci, 13: 1149–1154.

Gouin T., Mackay D., Jones K. C., Harner T., Meijer S. N. (**2004**). Evidence of "Grasshopper" effect and fractionating during long range atmospheric transport of organic contaminants. Environ. Pollution, 128: 139-148.

Hagan N., Robins N., Hsu-Kim H., Halabi S., Morris M., Woodall., Zhang T., Bacon A., Richter D. B., Vandenberg J. (**2011**). Estimating historical atmospheric mercury concentrations from silver mining and their legacies in present-day surface soil in Potosí, Bolivia. Atmos Environ, 45: 7619–7626.

Holmes N. S., **Morawska** L. (**2006**). A review of dispersion modeling and its application to the dispersion of particles: An overview of different dispersion models available. Atmospheric Environ 40, 5902–5928.

Ifewodo (**2013**). http://www.premiumtimesng.com/.

Jayamurugan R., Kumaravel I. B., Palanivelraja I. S., Chockalingam M. P. (**2013**). Influence of temperature, relative humidity and seasonal variability on ambient air quality in a coastal urban area. Int J Atmospheric Sci, Article ID 264046, 7 pages.

Kesarkar A. P., Dalvi M., Kaginalkar A., Ojha A. (**2007**). Coupling of the weather research and forecasting model with AERMOD for pollutant dispersion modeling. A case study for PM_{10} dispersion over Pune, India. Atmospheric Environ, 41: 1976–1988.

Lakes Environmental (2010). AERMOD View Technical Specifications and Features. http://www.weblakes.com/, accessed in December 2012.

Langner C., **Klemm** O. (**2011**). A comparison of model performance between AERMOD and AUSTAL 2000. J Air Waste Manag Assoc, 61: 640-646.

Lee S. S., **Keener** T. C. (**2008**). Dispersion modeling of mercury emissions from coal-fired power plants at Coshocton and Manchester, Ohio. Ohio J Sci, 108: 65-69.

Leonardo (**2013**). Cleaner and Greener. Leonardo Transportation Programme Academy.

Ma J., Yi H., Tang X., Zhang Y., Xiang Y., Pu L. (**2013**). Application of AERMOD on near future air quality simulation under the latest national emission control policy of China: A case study on an industrial city. J Environ Sci, 25: 1608–1617.

Makra L., Sánta T., Matyasovszky I., Damialis A., Karatzas K., Bergmann K., Vokou D. (**2010**). Airborne pollen in three European cities: Detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories. J Geophys Res, 115: D24220.

Ocak S., **Turalioglu** F. S. (**2008**). Relationship between Air Pollutants and Some Meteorological Parameters in Erzurum, Turkey. Global Warming, pp 485-499.

Oliver D. B., Cabelli R. J., Dolan K. M., Jarosik G. P. (**1990**). Azide-resistant mutants of *Escherichia coli* alter the SecA protein, an azide-sensitive component of the protein export machinery. Proc Natl Acad Sci USA, 87: 8227-8231.

Oluleye A. (**2012**). Modeling dispersion of air pollutants from a Liquified Natural Gas facility in Bonny, Nigeria. A ph.D thesis in the Department of meteorology, Federal University of Technology, Akure.

Paine R. J., Lee J. T., Cimorelli A. J., Perry S. G., Wilson D. J., Weil J. C., Venkatram A. (**1998**). AERMOD Performance Evaluation. (submitted) J Appl Meteor.

Perry S. G., Cimorelli A. J., Paine R. J., Brode R. W., Weil J. C., Venkatram A., Wilson R. B., Lee R. F., Peters W. D. (**2005**). AERMOD: a dispersion model for industrial source applications. Part II: model performance against 17 field study databases. J Appl Meteorol, 44: 694-708.

Perry S. G., Venkatram A., Weil J. C., Paine R. J., Wilson R. B., Lee R. F., Peters W. D., Brode R. W. (**2005**). AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. J Appl Meteorol, 44: 682-693.

Seinfeld J. H., **Pandis** S. N. (**2006**). Atmospheric Chemistry and Physics: from Air Pollution to Climate Change. Wiley, New York, 1225 pages.

Sonibare J. A., Akeredolu F. A., Obanijesu E. O. O., Adebiyi F. M. (**2007**). Contribution of volatile organic compounds to Nigeria's airshed by petroleum industry. Petrol Sci Technol, 25: 503-516.

Spadaro J. V. (**1999**). Quantifying the Damages of Airborne Pollution: Impact Models, Sensitivity Analyses and Applications. Ph.D. Thesis, Ecole des Mines de Paris, Centre d'Energetique, France, 130 pages.

US EPA (**2000**). Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and ComplexTerrain) Dispersion Model and Other Revisions; Final Rule. 40 Federal Register, pp. 68218.

Zhang Y., Liu X. H., Olsen K. M., Wang W. X., Do B. A., Bridgers G. M. (**2010**). Responses of future air quality to emission controls over North Carolina, Part II: Analyses of future–year predictions and their policy implications. Atmospheric Environ, 44: 2767–2779.

Citation: Happiness R. O., Ogunniran B. I., Oluleye A. (2019). Modeling of Gaseous Pollutants Dispersion of a Fossil Fuel-Fired Power Plant at Omotosho, Ondo State, Nigeria. Adv Sci Tech Res, 5(2): 9-36.