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Observation and forecast of NO_2 emissions using satellite data for Ghana

Abstract

This work presents nitrogen dioxide (NO_2) measurements from the Ozone Monitoring Instrument (OMI) satellite sensor. The data was processed with MATLAB neural network time series prediction algorithm to forecast NO_2 concentration in Ghana by the year 2020. The average NO_2 and UV aerosol index data over Accra from 2005 to 2015 was analyze with Levenberg- Marquardt method for machine learning model, which forecast indicated that NO_2 increased to 5.00×10^{15} molecules cm^{-2} with UV aerosol index of about-2.5. Averaged NO_2 over a period of 2005 to 2015 for Ghana were observed which indicated that, in 2005 NO_2 concentration in Ghana was measured as 0.692×10^{15} molecules cm^{-2} with UV aerosol index of about 4.0, which increased to 0.81×10^{15} molecules cm^{-2} with aerosol index of about 5.2 in 2010. This paper also examined the changes of monthly Ozone layer surface depletion from January to July 2010 over Africa due to NO_2 emission and shows that higher NO_2 emission concentration was found in the Tema Industrial Area and Agbogbloshie areas in Accra. The sources were identified and their evolution increased in the following order of years, October 2005, 2008, 2010 and 2013. Hence, to reduce the effect, the paper proposed a Biological Nitrogen Fixation (BNF) mathematical model for Accra using ecosystem capturing technology and CO_2 capturing technology for factories as well as reducing of human activities like deforestation in Ghana.

Keywords: ozone layer, nitrogen dioxide, machine learning, MATLAB, nitrogen fixation, ozone monitoring instrument

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Abbreviations: NO_2, nitrogen dioxide; OMI, ozone monitoring instrument; BNF, biological nitrogen fixation; PM, particulate matter: CO_2, carbon dioxide; SO_2, sulfur dioxide

Introduction

Coal is one of the most abundant energy sources in the world.[1] There are many advantages and societal benefits of burning coal and natural gas for electricity, heating and cooling, and even transportation. However, there are also some Environmental impacts associated with burning fossil fuels, including the release of emissions through flue gas. Nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), particulate matter (PM) and water vapor are all products of fossil fuel combustion. Nitrous oxide is a naturally produced greenhouse gas, but the flux has increased in the world due to it emissions from industrial countries as shown in Figure 1. Regulations require power plants to reduce NO_x, SO_2, and PM through the use of scrubbers and flue-gas desulfurization.[1] Naturally found in the atmosphere, CO_2 is not considered a pollutant. The CO_2 being released from burning fossil fuels was part of the atmosphere millions of years ago before being captured by plants and sea organisms. However, there has been increasing concern about the buildup of CO_2 and NO_2 concentrations in the atmosphere. International scientific consensus has concluded that the increase of CO_2 and NO_2 in the atmosphere is one of the causes of global climate change.[1] CFCs are man-made and highly efficient as greenhouse gases, however because of their detrimental effect on the ozone layer as shown in Figure 2 for Africa. Exposure to high levels of air pollution can cause a variety of adverse health outcomes. It increases the risk of respiratory infections, lung cancer, heart disease, and stroke.[2] Both short and long term exposure to air pollutants have been associated with health impacts. More severe impacts affect people who are already ill, children, the elderly and poor people are more susceptible. The 2011-2014 declines in Chinese emissions are more consistent with projections based on fully implemented emission controls.[3] Although air quality in developed countries has been generally improved over the last decades, the adverse health effects of particulate air pollution, even at relatively low level, remain a global public health concern in developing countries.[4] The disease burden associated with ambient air pollution worldwide is 3.7million premature deaths which were attributable to ambient air pollution in 2012.[5] About 88 percent of these deaths occur in low and middle income countries. The regional breakdown for low and middle income countries;[5] the Western Pacific is 1670000 deaths, South East Asians regions are 936000 deaths, Eastern Mediterranean region is 236000 deaths, Europe is 203000 deaths, Africa 176000 deaths, and Americas is 58000 deaths. Reducing ambient air pollution will cut emission of short-lived climate pollutants, particularly black carbon which is a major component of soot emissions from diesel vehicles, and other sources, as well as greenhouse gases contributing to longer term climate change impacts. Climate change produces a number of adverse effects on heath; this includes those from drought and extreme weather events like windstorms and floods, such as water- borne and food-borne diseases. It also increases the prevalence of vector-borne diseases like dengue or malaria.[6] Reducing the public health impacts of ambient air pollution requires addressing the main sources of the air pollution, including inefficient fossil fuel combustion from motor vehicle transport, power plants generations and improving energy efficiency in homes, buildings and manufacturing.[7] This paper seeks to show the increase of nitrogen-oxide NO_x in the industrial areas of Accra Ghana, using NASA space satellite technology data from October 2003 to 2015.

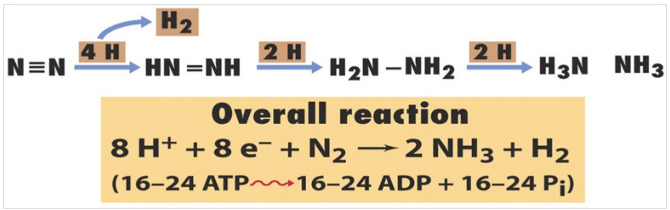

Figure 1 Biological Nitrogen Fixation Reaction.

Data and analysis

Satellites provide an ideal platform for closing this information gap, particularly for remote or otherwise inaccessible locations. There are a variety of methods used to derive NO_2 emission information from satellite measurements, but most rely on prior knowledge of the location of the source.[7] The Giovanni Air Quality instance combines global atmospheric aerosol and cloud data from MODIS, global atmospheric aerosol data from OMI, and ground-base Fine Particulate Matter data.[8] The Ozone Monitoring Instrument on the EOS Aura satellite provides data from instrument which gives daily level 3 global gridded ozone products at two spatial resolutions: high resolution 0.25 by 0.25 (OMTO3E) and TOMS like 1.0 by 1.25 (OMTO3D) as shown in Figure 2 for Africa. Giovanni-3 is a system which utilizes a variety of software package such as IDL, Gr ADS and Python and analytical functions.[8]

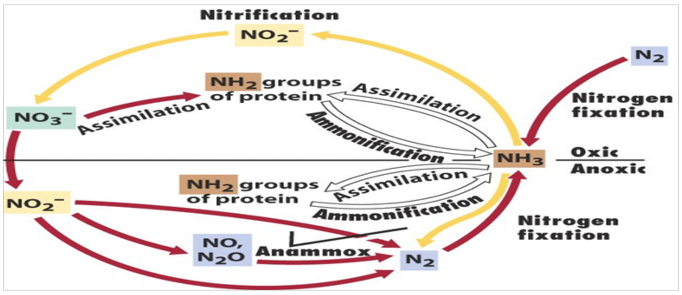

Figure 2 Nitrification Prominent in soil, water and sewage.

Methodology

Neural network prediction modelling

The Levenberg-Marquardt method was selected for the training algorithm which is recommended for most problems compared to Bayesian Regulariation which is for some noisy and small problems.[9] The Levenberg-Marquardt method is a compromise between Newton's method and Gradient descent. Newton's method which converges rapidly near a local or global minimum, but may also diverge. Gradient descent which is assured of convergence through a proper selection of the step-sie parameter, but converges slowly.[10] The Neural Network Time Series Tool in MATLAB was then used to model a two-layer feed forward network, with a sigmoid transfer function in the hidden layer and a linear function in the output layer as shown in the Figure 3 below. The dynamic network uses tapped delay to store previous values of the $x(t)$ and $y(t)$ sequences. When a network contains delays, the input to the network would normally be a sequence of input vectors that occur in a certain time order. The order of inputs is important when they are a sequence. In this case, the current output is obtained by multiplying the current input by $(t-1)$ and the preceding input by $(t-2)$ and summing the result. The output of NARX network, $y(t)$ is fed back to the input of the network through delay, since $y(t)$ is a function of $y(t-1)$, $y(t-2)$, …, $y(t-d)$.[10] However for efficient training this feedback loop can be opened.[10] This input and output model function equation is written as follows:

$$Y(t) = f\left(x(t-1), \ldots, x(t-d)\right) \qquad \text{Equation (5)}$$

The NARX model provide better prediction because it uses the additional information contained in the previous values of y(t) would not be available. The output of NARX is as show in Figure 4 below after inputing the data from Figure 5 & Figure 6 then simulated. This shows that if technological measures are not put in place to reduce NO_2 emission by 2020 the annual NO_2 will increase to about 5×10^{15} molecules/cm^2. Hence this paper has proposed two technological solution in the next section.

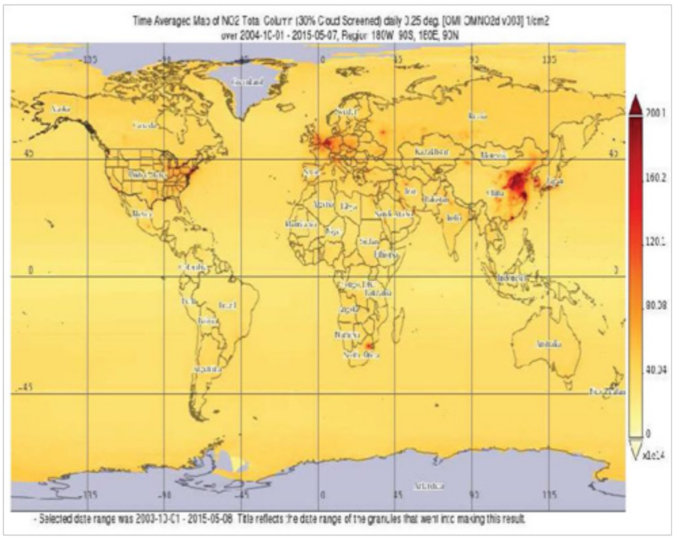

Figure 3 NO_2 emissions from industrial countries.

Application field of technology

The long term balance between gains and losses of nitrogen is a dominat control on productivity and carbon storage for many ecosystem.[11] The model includes deposition of mineral nitrogen, combining deposition of NO_y and NH_x from the atomosphere and biological nitrogen fixation as the sources of new mineral nitrogen entering terrestrial ecosystems. Both sources are assumed to enter the soil mineral nitrogen pool directly. Atmospheric deposition is prescribed as an annual rate for each grid cell, with the option of providing a time varing field. Values are time-interpolated if necessary to produce a smoothly varing field at each grid cell. Biological nitrogen fixation $\left(BNF, gNm^{-2}y^{-1}\right)$ is estimated as a function of annual net primary production $\left(NPP, gCm^{-2}y^{-1}\right)$ in Accra, as:

NPP=0.0099× Rang of Years-19.09 ----------- equation 1

BNF=1.8[1- exp(- 0.003NPP)] ----------- equation 2

BNF=1.8[1-exp(- 0.003(0.009× Rang of Years-19.09))] ----------- equation 3

BNF=1.8[1- exp(- 0.000027× Rang of Years+0.05727)] ----------- equation 4

Biological nitrogen fixation is known to be a key to sustain agriculture and to reduce soil fertility decline. Research on microorganisms and plants able to fix nitrogen contributes largely to the production of biofertilizers.[12] Biological nitrogen fixation estimate that amount of fixed nitrogen and to select the most effective rhiobial strain plant genotype combination. The production of nitrogen fertilizer by industrial fixation generates large quantities of carbon dioxide, contributing to earth warming. The natural process of BNF offers an economic means of reducing environmental problems and improving the internal resources. It is a process that allows microorgaisms to convert atomospheric nitrogen (N_2) to ammonia (NH_3) assimilable by associated plants. The reaction shown in diagrame 1 indecates the N_2 fixed to NH_3 and NH_2 groups, this is done by Prokaryotes-Bacteria and Archaea. Soil enrichment is done using NH_3 media with aeration as shown in diagrame 2, done in two step process-ammonia then nitrite oxidation NH_3+O_2 yields NO_2+H_2O+ATP, Nitrosomonas and NO_2+O_2 yields NO_3+ATP, Nitrobacter (Figure 1 & 2).

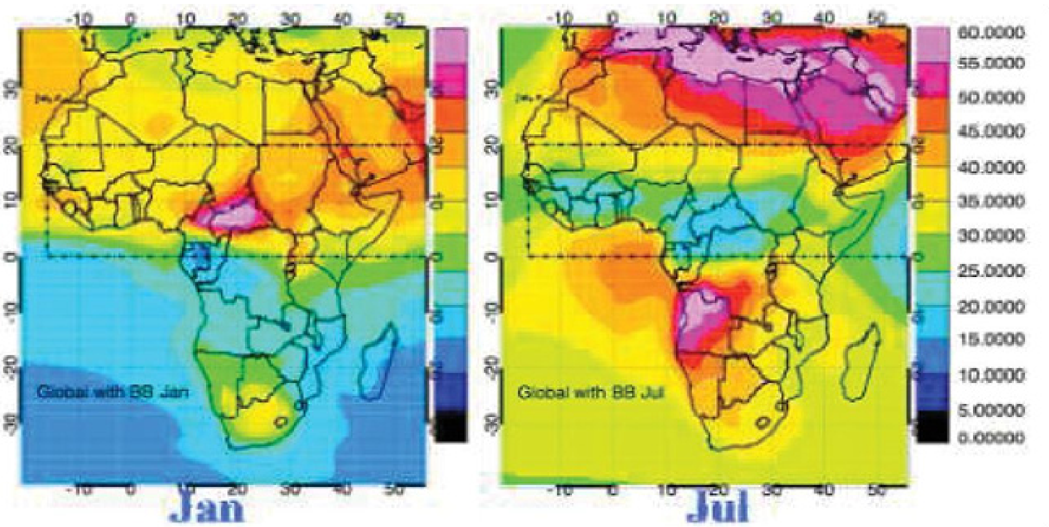

Figure 4 Satellite detection of monthly surface ozone depletion for Africa in 2010.

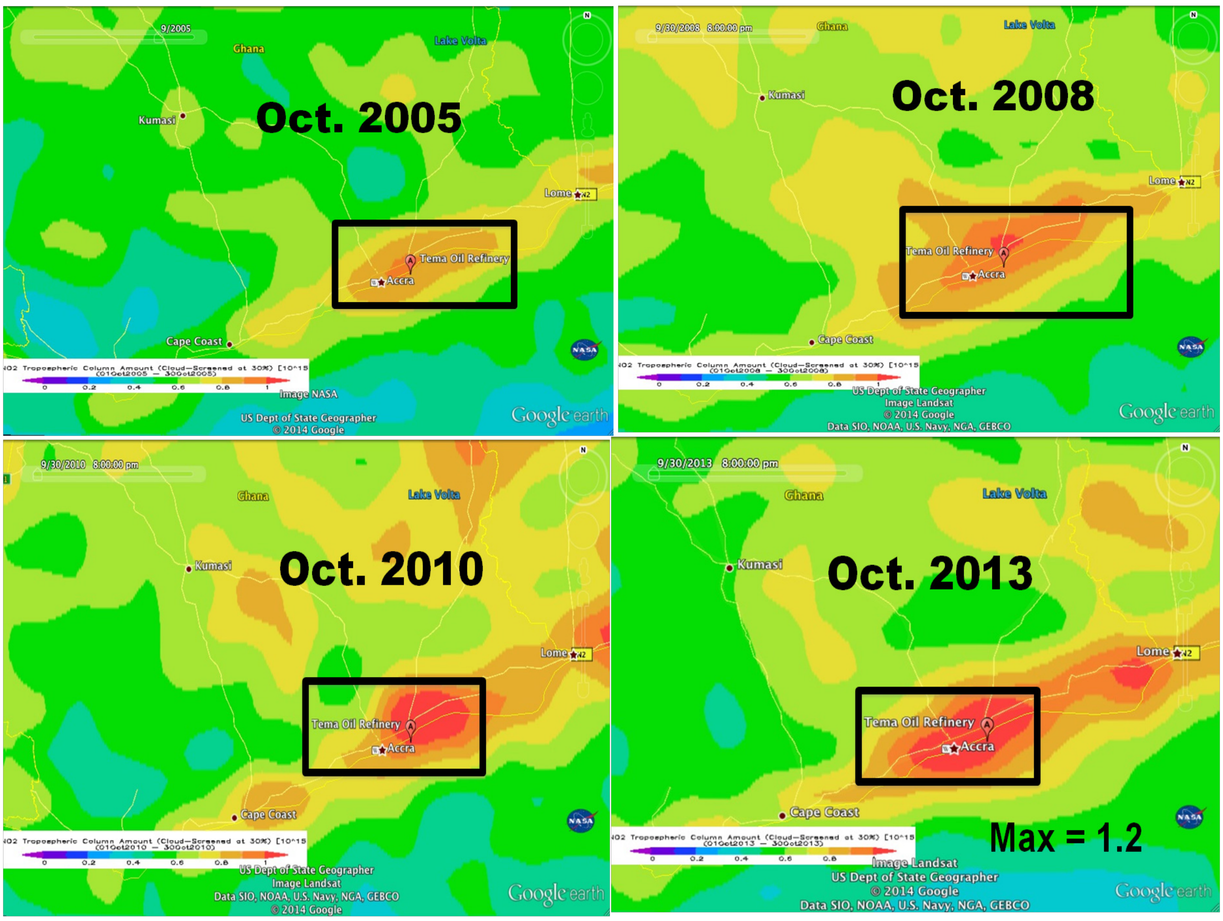

Figure 5 Satellite detection of NO_2 emission sources in Greater Accra.

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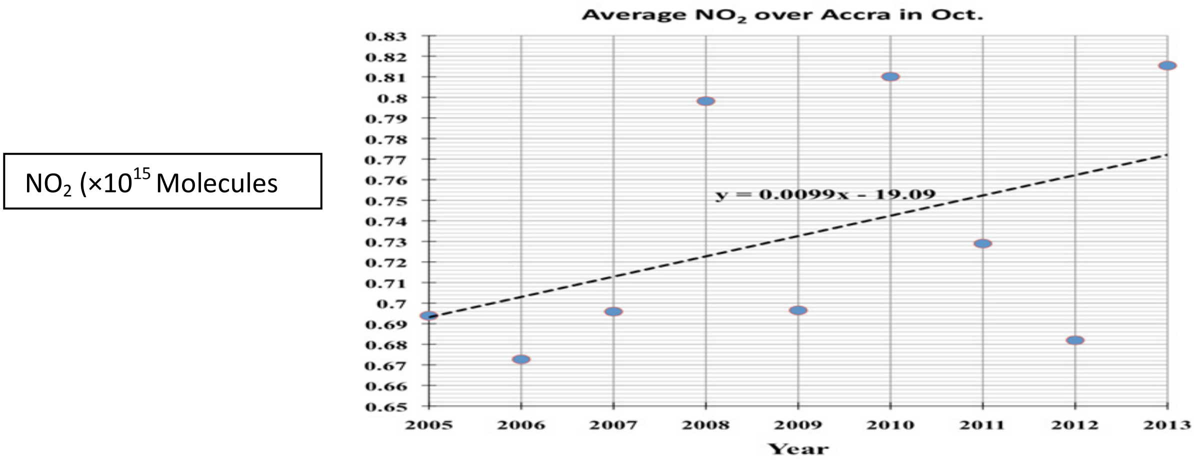

Figure 6 Average NO_2 over Greater Accra from satellite detection.

This paper shows that NO_2 emission in Accra is done by most of the factories in Tema and Agbogbloshie scrap yard which lead to great concerns as shown in Figure 7. The gas created by burning of fossil fuels in a power plant called flue gas, majority of flue gas is atmospheric nitrogen and water vapor with CO_2 making up 4 to15 percent of the end product.[13] In post-combustion capture, the flue gas would continue on, passing through a vessel containing a chemical solution such as aqueous amines (nitrogen containing organic compounds) or chilled ammonia (NH_3). The CO_2 bonds with the chemicals creating a concentrated CO_2 solution. The solution is then heated to release the CO_2 and the absorbing chemicals are recycled back to the beginning of the process. Before entering the atmosphere, flue gas is treated by scrubber and flue gas sulferization technologies, which remove impurities. The capture technique will be used in other industries, such as natural gas and refinery treatment plants, and utilizes well understood technologies within the current context. The energy efficiency of a CO_2 capture plant depends primarily on the performance of the solvent and optimization of the plant. Hence Ghana will be the first Sub-Sahara Africa country to implement it and this will lead in building capacity in this technology.

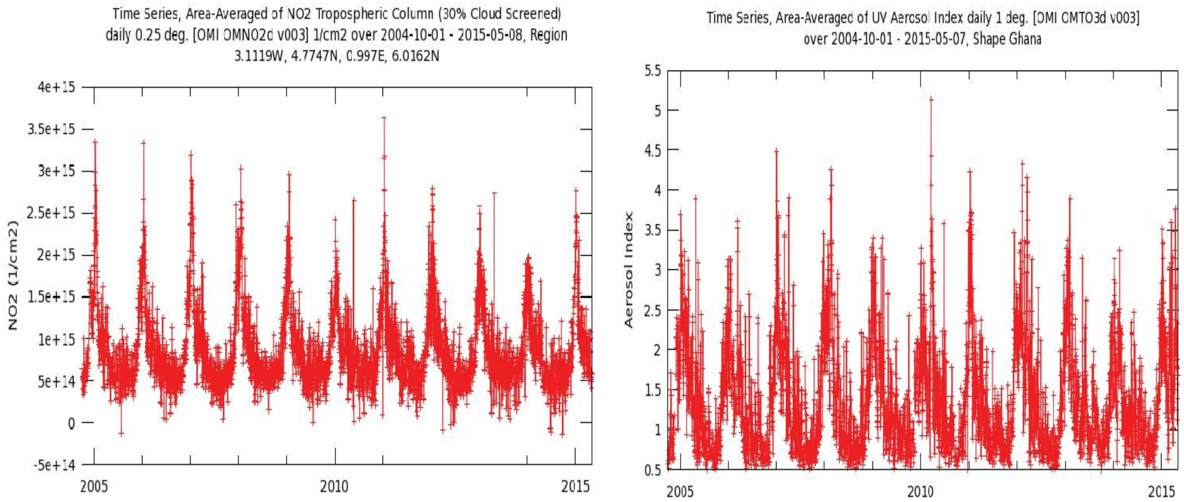

Figure 7 Satellite detection of NO_2 and Ultra Violet time series Area – Averaged.

Discussion and conclusion

The studies for Ghana about imports of new and used electrical and electronic revealed that in 2009, around 70% of all imports were used electrical and electronic equipment. Second-hand imports were estimated to be 30% of non-functioning which are e-waste. Half of this amount was repaired locally and sold to consumers and the other half was unrepeatable, this was about 40,000tonnes of e-waste in 2010.[14] These e-waste ends up in Agbogbloshie scrap yard resulted in NO_2 increased in 2010 and 2011 as shown in Figure 8. Findings made in April 2005 and April 2006 by EPA-Ghana on gaseous pollutants such as NO_2 concentration measured at both the permanent and roadside sites were below the 24-hour EPA-Ghana guideline of 0.075ppm and above the annual WHO guideline of 0.02ppm. The findings also indicated that 12 of the 16 samples collected at the roadside location were above the annual WHO guideline of 0.02ppm.[15] Comparing the ground findings to the satellite observation as shown in Figure 9, it can be estimated that NO_2 concentration in Accra need to be reduced. Hence the benefit of this capture technique is that it can be used in industries, such as natural gas and refinery treatment plants. The food and beverage industry can use this technology to provide CO_2 for liquid and food preservation in Ghana. Fertilizer manufacturing can use CO_2 as a feedstock for farms in Ghana. The construction industry can use CO_2 for concrete manufacturing. The CO_2 capture from the coal fired power plant will be designed to produce about 3307 ton per day. This is mainly due to processing a larger flair gas with higher

CO_2 content in the coal power plant. The CO_2 recovery for both coal power plants will be about 90%. The diameter of absorber in coal power plant will be 32.8ft. The Regenerator diameter for coal power plant will be 19.7ft. In conclusion if this technology is implemented the country will reduce the effect of climate change and this will go a long way in helping to protect our ecosystems.

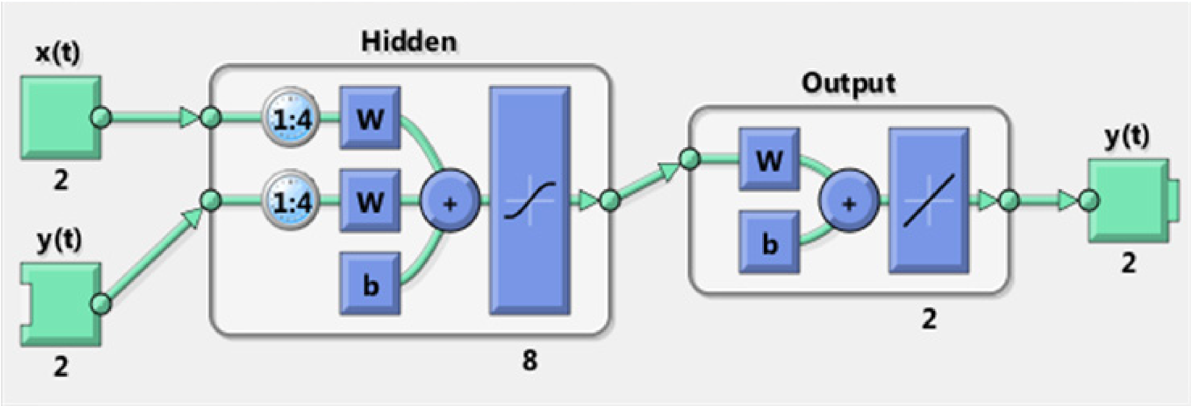

Figure 8 A two layer feed-forward network with sigmoid transfer function.

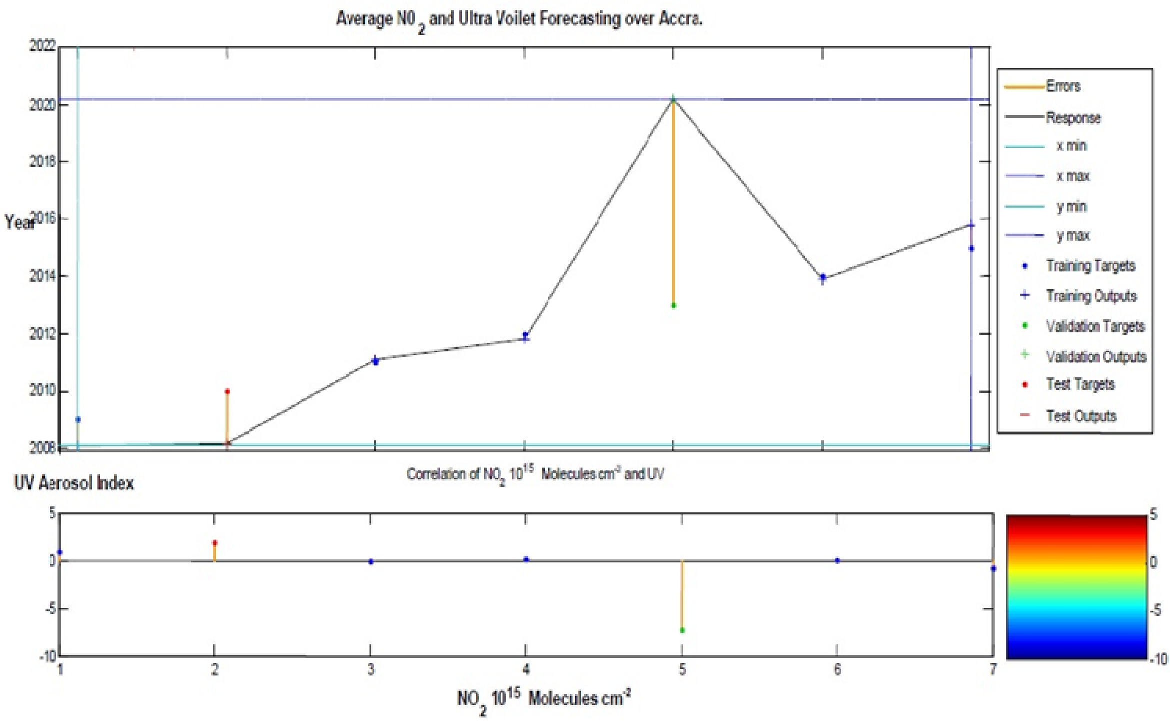

Figure 9 Forecast of average NO_2 emission and Ultra Violet index for Greater Accra.

Acknowledgement

None.

Conflict of interest

The author declares no conflict of interest.

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