Evaluation of Pollutants Along the National Road N2 in Togo using the AERMOD Dispersion Model

Yawovi Mignanou Amouzouvi, Milohoun Mikeokpo Dzagli, Koffi Sagna, Zoltán Török, Carmen Andreea Roa, Alexandru Mereuță, Alexandru Ozunu, Kodjovi Sidéra Edjame

© Pure Earth

Introduction

Atmospheric pollution refers to the presence of pollutants (gaseous or particles) in the atmosphere. Air pollution can have harmful effects on the environment and human health. The sources of this pollution can be either natural or related to human activities, especially combustion processes (motor vehicles, industrial installations, energy production, etc.). Many studies have shown a correlation between the degradation of the environment and human health and the presence of pollutants in the atmosphere. Exposure to air pollution is responsible for respiratory and lung diseases and leads to premature deaths worldwide (4.2 million in 2016 according to the World Health Organization (WHO)). Pollution contributes to climate change and the phenomena of acid rain which has a very harmful effect on vegetation and global warming. Sulfur dioxide, emitted from fossil fuel consumption or industrial activities, is an acidifying gaseous pollutant that forms sulfuric acid in the presence of water. It contributes to the phenomenon of acid rain that disrupts the composition of air, surface water and soil, and could damage plants and vegetation and kill animal species. At higher concentrations, sulfur dioxide can have serious health effects and impact pulmonary function. Apart from industrial processes, road traffic is...
an important source of atmospheric pollution in the world, especially in developing countries, due to the age of vehicles used and poor quality of fuel. Nitrogen oxides constitute very toxic odorant gases, and are formed by the oxidation of nitrogen in the air, from fuels with oxygen or during the combustion phenomena in engines. They have harmful effects on human health and the environment with the formation of ozone (related to the greenhouse effect), and increased sensitivity of the bronchi to microbial infections for children. For nitrogen dioxide (NO₂), a traffic-related pollutant, short-term exposure causes significant inflammation of the respiratory tract, reduces lung function and increases symptoms of bronchitis in those with asthma.

Particulate matter (PM) is comprised of ultrafine particles that impact human health. These small aerosols can penetrate deep into the lungs and into the alveoli. Nuclei condensation can be formed where moisture and pollutants (lead, sulfur dioxide) can absorb, making them even more toxic. Therefore, PM is an important vector of respiratory tract intoxications in areas of high traffic. Diallo and coworkers demonstrated the correlation between air quality and its impact on respiratory diseases due to PM in Lomé, Togo. Air pollution in urban areas due to road traffic is an important issue in developing countries. Globally, many countries have little or no access to low-sulfur fuel, and do not have standards for vehicle emissions. The sulfur content in fuel in most developed countries is currently 50 ppm sulfur or less; however high sulfur content can be found in many low- and middle-income countries from ranges of 500-5000 ppm. Transport traffic is estimated to grow rapidly by 2050, which will double global fuel demand. Almost 50% of the fuels imported to West Africa come from Amsterdam, Rotterdam and Antwerp, and trade statistics showed that 80% of the diesel exported to Africa has a sulfur content at least 100 times above the European standard.

In Togo, more than 50000 motorcycles and taxis travel on traffic roads daily, polluting the atmosphere, and as a result the population has respiratory problems due to the poor quality of fuels that these vehicles consume. The N2 is an international road not only used by vehicles from Togo, but cars and buses from Nigeria and Benin travel through to Togo, Ghana and the Côte d’Ivoire and vice versa. In Togo and along the National Road N2, even in Benin and Nigeria, the most used fuels are adulterated with unknown contents of sulfur (locally called “Boudé” or “Kpayo” in Togo and Benin). It is thus necessary to determine air pollution in this area.

Five West African countries including Togo introduced standards to regulate emissions and lower the levels of sulfur diesel in their fuels in 2016. Many studies have been carried out in countries using AERMOD simulation for the measurement and control of air quality and assessment of their impact on human health and the environment. For example, Yadav et al. studied PM, sulfur dioxide (SO₂) and nitrogen oxide (NOₓ) ground level concentrations using air modeling with AERMOD model in an industrial area located about 20 km from Tumkur in Bangalore (India). They found maximum concentrations at 1770 m of NOₓ at 24 µg/m³, of SO₂ at 1.2 µg/m³ and for PM at 0.0028 µg/m³. Gibson et al. evaluated the concentration of PM₁₀, NOₓ and SO₂ in a rural area (Nova Scotia) and urban area (Halifax) in Canada using the AERMOD Gaussian plume air dispersion model. Their findings showed that the pollutant concentrations in Nova Scotia were lower than in Halifax: 0.1 < 2.5 µg/m³, 0.1 < 4.0 µg/m³ and 0.16 < 1.0 µg/m³ for PM₁₀, NOₓ and SO₂, respectively. Amoatey et al. estimated the concentrations of SO₂, NOₓ and PM emitted in Tema Oil Refinery (Ghana) using AERMOD and CALPUFF models across seasons. The obtained maximum daily concentrations were higher during the heavy rainy season than minor rainy and dry seasons (37.7 µg/m³ for SO₂, 9.6 µg/m³ for NOₓ and 38.8 µg/m³ for PM₁₀), respectively.

The National Road N2 of Togo, from Lomé to the Aného toll, covers a distance of 15.4 km and heavily trafficked by vehicles from the Gulf of Guinea countries. Particulate matter, SO₂ and NOₓ, are the main pollutants from road traffic and industries. Few studies have been conducted on air quality and fuel quality in Togo. It is thus necessary to evaluate the concentration of these pollutants in the air along the National Road N2. The results will be useful for the assessment of air pollution impacts on users, the health of nearby residents and the surrounding ecosystem using the most predictable modeling system, AERMOD.

| Abbreviations | Description |
|---------------|-------------|
| PM | Particulate matter |
| UTM | Universal Transverse Mercator |
| WHO | World Health Organization |
The objective of the present study was to estimate the concentration of $\text{SO}_2$, $\text{NO}_x$ and PM emitted along the N2 in Togo in order to determine the pollution rate compared to international standards set by the WHO. This study could be useful for decision makers setting air quality policies for the future, in order to monitor the emissions of atmospheric pollutants, and for future studies as a baseline on the health of the population in the country.

**Methods**

This study was carried out on the national road of Togo, the National Road N2, from Lomé to the Aného toll, which travels over a distance of 15.4 km (Figure 1). The National Road N2 (Lomé-Aného), about 50 km long, lies along the coast of Gulf of Guinea. The present case study focused on the evolution of air quality in the highly trafficked area for pollutants ($\text{SO}_2$, $\text{NO}_x$, and PM emissions). Figure 1 presents a road map of south Togo and a Google map photo of the study area along the National Road N2.

**Model set up**

The Industrial Source Complex Short Term Version 3 model, which is included in the United States Environmental Protection Agency (USEPA) Regulatory Model, AERMOD View software, was used to perform the dispersion simulations of pollutants. The model was used to predict air concentrations and ambient impacts around the point/area and volume sources. The emission rates and the meteorological conditions were used as model inputs. Meteorological data, such as air temperature, wind speed, wind direction, ceiling height, cloud cover, pressure, relative humidity, and precipitation were obtained from the local station at Lomé (Togo) for the
Figure 2 shows the flow and explains the processing of data during the detection of atmospheric pollutants in AERMOD. The model is composed of three parts as described by Yadav and coworkers: AERMOD meteorological preprocessor (AERMET) to extract meteorological data and to assess data quality; AERMOD terrain preprocessor (AERMAP) to merge all data available over a 24-hour period and record them in a single file; and AERMOD Gaussian plume model that reads the merged meteorological data and estimates the boundary layer parameters for the dispersion calculations. The main program was AERMOD, while data were pre-processed in AERMET and AERMAP.

Meteorological data such as wind speed, wind direction, temperature, and cloud cover were input to AERMET to determine the boundary layer parameters. AERMAP uses geological data to calculate the terrain height scale and to create receptor grids before passing receptor characteristics to AERMOD for final processing. Lastly, the source data were sent directly to AERMOD for processing. In addition, the wind rose plot for the most predominant wind direction and the pollutant contents were collected. The concentrations calculations are based on the following hypotheses: (i) the pollution sources were only the vehicles traveling along the selected road segment (total of 15.4 km); (ii) no other pollution sources were considered; (iii) the source was a line volume source with a width the same as the road (20 m) and a mixing layer height of 2 m. The concentration was calculated using the European Monitoring Evaluation Programme/European Environmental Agency air pollutant emission inventory guidebook, version 2016, considering the local traffic data and the highest uncertainty from the meteorological data. The original set of data contained daily average values and it was converted to hourly values in order to fit with the model. The concentration estimation methodology covered exhaust emissions of NOx, SO2, PM contained in the fuel. Nitrogen oxide emissions were further split into nitric oxide and NO2.

For exhaust emissions of NOx and PM, the algorithm Tier 1 approach was used, following Equation 1.

\[ E_i = \sum_j \left( \sum_m (FC_{j,m} \times EF_{i,j,m}) \right) \]

where, \( E_i \) is the emission of pollutant “i” (g); \( FC_{j,m} \) is the fuel consumption of vehicle category “j” using fuel “m” (kg); and \( EF_{i,j,m} \) is the fuel consumption-specific emission factor of pollutant “i” for vehicle category “j” and fuel “m” (g/kg).

Vehicles were categorized as passenger cars, light commercial vehicles, heavy-duty vehicles or L-category vehicles (which includes two or three wheelers, quadricycles and micro cars) and the considered fuels included petrol, diesel and natural gas. Tier 1 mean emission factors of NOx and PM are presented.

### Table 1 — Tier 1 — Typical NOx and PM Content of Fuel

| Category                          | Fuel                        | NOx (g/kg fuel) mean | PM (g/kg fuel) mean |
|-----------------------------------|-----------------------------|----------------------|---------------------|
| Passenger car                     | Petrol                      | 8.73                 | 0.03                |
|                                  | Diesel                      | 12.96                | 1.10                |
|                                  | Liquefied Petroleum Gas     | 15.20                | 0.00                |
| Light Commercial Vehicle         | Petrol                      | 13.22                | 0.02                |
|                                  | Diesel                      | 14.91                | 1.52                |
| Heavy-duty vehicle                | Diesel                      | 33.37                | 0.84                |
|                                  | Compressed Natural Gas (Buses) | 13.00              | 0.02                |
| L-category (2/3 wheelers, quadricycles and micro cars) | Petrol | 6.64 | 2.20 |
Examples of fuel sulfur content periods can be found in Table 2.

The emissions of $\text{SO}_2$ per fuel-type $m$ can be estimated by assuming that all sulfur in the fuel was transformed completely into $\text{SO}_2$, using Equation 2.

\[
E_{\text{SO}_2,m} = 2K_{s,m} \times FC_m
\]

where, $E_{\text{SO}_2,m}$ is the emissions of $\text{SO}_2$ per fuel "m" (g); $K_{s,m}$ is the weight related to sulfur content in fuel of type "m" (g/g fuel); and $FC_m$ is the fuel consumption of fuel "m" (g).

In the case of Togo, the sulfur content limit in 2018 is given in Table 3 from the Fuel Quality and Emission Standard Developments in Africa.

Our investigations on transportation in Togo provide a characterization of traffic levels along the N2 (Table 4). We identified almost 10,000 vehicles in 24 hours.

### Results

A wind rose diagram illustrates the speed, direction and frequency of winds of a given location using a center coordinate system. Meteorological pre-processed data were used to determine the corresponding wind rose plot (Figure 3), which shows the most predominant wind direction. The wind rose presented a main wind direction of south-west with an annual probability up to 38% and average wind speed between 3.6 - 5.7 m/s. Secondary directions were mainly west and northwest with a probability up to 12% and wind speed up to 8.8 m/s.

### AERMOD dispersion modeling results

Hourly, daily and annual averages of concentrations of pollutants ($\text{SO}_2$, $\text{NO}_x$, and $\text{PM}$) were investigated along the National Road N2, by AERMOD simulations. The maximal concentrations of emitted $\text{SO}_2$, $\text{NO}_x$ and $\text{PM}$ obtained through AERMOD were compared with permissible limits.
of the WHO in Table 5.29

Concentration distribution of Nitrogen oxides

Simulations were performed for the concentration of NO\textsubscript{x} along the National Road N2. Figures 4-6 present estimations of the maximum hourly, daily and annual concentrations of NO\textsubscript{x} on the National Road N2, respectively. The AERMOD simulation showed that the maximum hourly (Figure 4) and daily (Figure 5) average concentrations of NO\textsubscript{x} were 16.78 μg/m\textsuperscript{3} and 9.89 μg/m\textsuperscript{3}, respectively, at the position of the road where the Universal Transverse Mercator (UTM) coordinates were 313734 m E and 681400 m N. The maximum annual average concentration obtained on the road was 2.46 μg/m\textsuperscript{3} at the position of the road with the UTM coordinates of 315934 m E and 682000 m N (Figure 6).

Concentration distribution of sulfur dioxide

Concentration simulations performed for SO\textsubscript{2} emitted on the National Road N2 are presented in Figures 7-9 for hourly, daily and annually concentrations, respectively. The maximum average concentrations of SO\textsubscript{2} emitted on the road were 71.91 μg/m\textsuperscript{3} for hourly concentrations (Table 5 and Figure 7), 42.41 μg/m\textsuperscript{3} for daily concentrations (Figure 8) and 11.23 μg/m\textsuperscript{3} for annual concentrations (Figure 9) at the UTM coordinates of 313734 m E and 681400 m N.

Concentration distribution of particulate matters

For PM, the model did not yield any valuable graphical representations, due to the very low obtained concentrations. In all AERMOD simulations, the PM concentration was low, as shown in Table 5, and

| Pollutant gas | Time average | Maximum concentration [μg/m\textsuperscript{3}] | WHO air quality guidelines, 2005 [μg/m\textsuperscript{3}] |
|---------------|--------------|-----------------------------------------------|--------------------------------------------------|
| NO\textsubscript{x} | 1 hour | 16.78 | 200 |
| | 24 hours | 9.89 | - |
| | Annual | 2.46 | 40 |
| | 1 hour | 71.91 | - |
| | 24 hours | 42.41 | 20 |
| SO\textsubscript{2} | Annual | 11.23 | - |
| | 1 hour | - | - |
| | 24 hours | 0.62 | 25 |
| PM | Annual | 0.15 | 10 |

Table 5 — Maximum Concentrations Obtained for NO\textsubscript{x}, SO\textsubscript{2} and PM
Figure 4 — Maximum 1-hour average concentrations for NO$_x$.

Figure 5 — Maximum 24-hour average concentrations for NO$_x$. 

Amouzouvi et al
Figure 6 — Maximum annual average concentrations for NO$_x$

Figure 7 — Maximum 1-hour average concentrations for SO$_2$
Figure 8 — Maximum 24-hour average concentrations for SO₂

Figure 9 — Maximum annual average concentrations for SO₂
hourly concentrations were below the detection level of the software. Daily and annual maximum average concentrations for PM, using AERMOD, were as low as 0.62 µg/m³ and 0.15 µg/m³, respectively, at the position of the road where UTM coordinates were 313734 m E and 681400 m N.

Discussion

The maximum hourly concentration for the NOx is lower than the permissible level of 200 µg/m³ recommended by the WHO. The annual maximum concentration for NOx is also lower than the permissible level of 40 µg/m³ set by the WHO. Concentrations of NOx on the National Road N2 according to AERMOD were much lower than the maximum permissible limits set by the WHO. These results are similar to the range of NO2 concentrations reported in other African cities, both hourly (9.4-135 µg/m³) and annually (2-175 µg/m³).

The maximum daily concentration of SO2 exceeded twice the permissible limit set by the WHO at 20 µg/m³ and is in agreement with the daily concentration range of SO2 emitted in African cities (0.2-3662 µg/m³). However, this result is lower than air pollution daily data for SO2 from Cotonou (Benin) at the crossroads of the Dantokpa market, which were reported to be as high as 784.8-3662.4 µg/m³, and a reported concentration in Dakar of 68.54 µg/m³. Average levels of SO2 on the National Road N2 were higher than data obtained in Cairo (34 µg/m³) and in Bamako (29.03 µg/m³). In western African cities, lower concentrations of 0.5 µg/m³ was reported in Ouagadougou (Burkina Faso) and (3.66 µg/m³) in Abidjan (Côte d’Ivoire). Lower concentrations below the permissible limit set by the WHO were found in some African towns, such as Marrakesh (Morocco) and Tunis (Tunisia). These results should alert public authorities to monitor SO2 emissions to avoid environmental and health consequences. The main sources of SO2 are from traffic and combustion in motors, and reduction of sulfur levels in fuel in West African countries is crucial.

The daily and annual maximum average concentrations of PM were lower than the permissible limit set by the WHO, of 25 µg/m³ and 10 µg/m³, respectively. The PM concentration results from the present study were lower than those reported by Diallo et al. in the town of Lomé, where annual mean concentrations for PM2.5 ranged from 10.3-17.3 g/m³ and 11.6-18.4 g/m³ for PM10, which are lower than the permissible values of the WHO. Annual concentration levels of PM2.5 in Tema (Ghana) refinery were 12.6 µg/m³, much higher than the results found in the present study.

Among the three studied pollutants emitted by engines on the National Road N2 in Togo, the concentration of SO2 was higher than the concentration of NOx and PM and exceeded the recommended value set by the WHO. Sulfur dioxide is associated with engine exhaust from industries and traffic, and the results of the present study indicate that the fuels available in West African countries, especially in Togo and neighboring countries, are heavily sulfured. Atmospheric pollution is caused by human activities. High concentrations of air pollutants are associated with increased risk of human disease in cities. For example, Val et al. showed that exposure to particulate pollution could lead to adverse health effects such as the cancer in western Africa. The WHO reported that the premature death toll globally in 2016 due to air pollution was 4.2 million. Environmental problems such as climate change and global warming are related to the impacts of pollutants. The present study should prompt the government to make decisions on pollutant emissions, protecting the environment and human life. In addition, it is hoped that the present study could help to bring a greater awareness of the real impacts of pollution on human health and the environment.

Conclusions

The present study reported on the dispersion and concentrations of different pollutants such as SO2, NOx and PM emitted on the National Road N2, in Togo, using AERMOD modelling with site-specific meteorological data. This road is heavily used by many types of vehicles traveling from Côte d’Ivoire, Ghana, Togo, Benin and Nigeria and adulterated fuels are regularly used, impacting human health and the environment. The results for these three pollutant gases showed that the hourly average concentration of SO2 was 71.91 µg/m³, 16.78 µg/m³ for NOx and PM had very low and undetectable concentrations. Daily average gas concentrations were 42.41 µg/m³ for SO2, 9.89 µg/m³ for NOx and 0.62 µg/m³ for PM. Results for annual concentrations were 11.23 µg/m³ for SO2, 24.46 µg/m³ for NOx and 0.15 µg/m³ for PM. These results showed that concentrations of NOx and PM were lower than the permissible limit of the WHO, similar to results in other African countries (9.4-135 µg/m³). However, the mean concentration of SO2 was almost twice the permissible limits set by the WHO (20 µg/m³). This illustrates the poor quality of fuel used in West African countries which may be very rich in sulfur. These results can assist in efforts by authorities to monitor pollutant levels in Togo. Efforts must be made to control the level of sulfur
contained in fuels to avoid harmful impacts of sulfur dioxide on human health and the environment. We recommend point monitoring on this road by measuring gas pollutants concentrations and an assessment on impact to local population health.

Acknowledgments
The authors would like to thank “Société Nouvelle de Phosphate du Togo (SNPT)” and African Spectral Imaging Network for their financial support and “Agence Universitaire de la Francophonie” for the Eugen Ionescu doctoral fellowship.

Copyright Policy
This is an Open Access article distributed in accordance with Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0/).

References
1. Manalisidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and health impacts of air pollution: a review. Front Public Health [Internet]. 2020 Feb 20 [cited 2020 Jul 8];8:Article 14 [13 p.]. Available from: https://doi.org/10.3389/fpubh.2020.00014
2. Guttikunda SK, Jawahar P. Evaluation of particulate pollution and health impacts from planned expansion of coal-fired thermal power plants in India Using WRF-CAMx modeling system. Aerosol Air Qual. Res. [Internet]. 2018 Dec [cited 2020 Jul 8];18(12):3187-202. Available from: https://doi.org/10.4209/aaqr.2018.04.0134
3. Penard-Morand C, Annesi-Maesano I. Air pollution: from sources of emissions to health effects. Breathe [Internet]. 2004 Dec [cited 2020 Jul 8];1(2):108-19. Available from: https://breathe. ersjournals.com/content/1/2/108
4. Wilson WE, Suh HH. Fine particles and coarse particles: concentration relationships relevant to epidemiologic studies. J Air Waste Manag Assoc. 1997 Dec;47(12):1238-49.
5. Morgernstern V, Zutavern A, Cyrys J, Brockow I, Gehring U, Koletzko S, Bauer CP, Reinhardt D, Wichmann HE, Heinrich J. Respiratory health and individual estimated exposure to traffic-related air pollutants in a cohort of young children. Occup Environ Med [Internet]. 2007 Jan [cited 2020 Jul 8];64(1):8-16. Available from: http://dx.doi.org/10.1136/oem.2006.028341
6. Marino E, Caruso M, Campagna D, Polosa R. Impact of air quality on lung health: myth or reality? Ther Adv Chronic Dis [Internet]. 2015 Sep [cited 2020 Jul 8];6(5):286-98. Available from: http://doi.org/10.1177/204062315587256
7. Ambient (outdoor) air pollution [Internet]. Geneva: World Health Organization; 2018 May 2 [cited 2020 May 29]. [About 11 screens]. Available from: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
8. Pope 3rd CA. Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who’s at risk? Environ Health Perspect [Internet]. 2000 Aug [cited 2020 Jul 8];108(suppl 4):713-23. Available from: https://doi.org/10.1289/ehp.108-1637679
9. Brauer M, Amann M, Burnett RT, Cohen A, Dentener F, Ezzati M, Henderson SB, Kryzanowski M, Martin RV, Van Dingenen R, van Donkelaar A, Thurston GD. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ Sci Technol [Internet]. 2012 Jan 17 [cited 2020 Jul 8];46(2):652-60. Available from: https://doi.org/10.1021/es2025752. Subscription required to view.
10. Smith K. Biofuels, air pollution, and health: a global review. New York: Plenum Press; 1987. 476 p.
11. Hu X, Zhang J, Mukhnahallipatna S, Hamann J, Biggs MJ, Agarwal P. Transformations and destruction of nitrogen oxides—NO, NO₂, and N₂O—in a pulsed corona discharge reactor. Fuel [Internet]. 2003 Sep [cited 2020 Jul 8];82(13):1675-84. Available from: https://doi.org/10.1016/S0016-2361(03)00979-6. Subscription required to view.
12. Amosayet P, Omidvarbarna H, Affum HA, Baawain M. Performance of AERMOD and CALPUFF models on SO₂ and NO₂ emissions for future health risk assessment in Tema Metropolis. Hum Ecol Risk Assess Int [Internet]. 2019 [cited 2020 Jul 8];25(3):772-86. Available from: https://doi.org/10.1080/10807039.2018.1451745. Subscription required to view.
13. Nhug NT, Amini H, Schindler C, Kutlar Joss M, Dien TM, Probst-Hensch N, Perez L, Kunzli N. Short-term association between ambient air pollution and pneumonia in children: a systematic review and meta-analysis of time-series and case-crossover studies. Environ Pollut [Internet]. 2017 Nov [cited 2020 Jul 8];230:1000-8. Available from: https://doi.org/10.1016/j.envpol.2017.07.063. Subscription required to view.
14. Saleh Y, Anthiérue S, Dusautoir R, Allemann LY, Sotty J, De Sousa C, Platel A, Perdrix E, Riffault V, Frouval I, Nesslany F, Canivet I, Garcon G, L-Guidice JM. Exposure to atmospheric ultrafine particles induces severe lung inflammatory response and tissue remodeling in mice. Int J Environ Res Public Health [Internet]. 2019 [cited 2020 Jul 8];16(7):Article 1210 [18 p.]. Available from: https://doi.org/10.3390/ijerph16071210.
15. Diallo A Hayaka A, Dossou-Yovo K, Asih M, Badjibaïsi E, Ketoh K. Etude de l’impact de la qualité de l’air sur la santé respiratoire des populations à Lomé (Togo) [Study of the impact of air quality on the respiratory health of populations in Lome (Togo)]. Toxicol Anal Clin [Internet]. 2020 Jun [cited 2020 Jul 8];32(2):120-6. Available from: https://doi.org/10.1016/j.toxac.2019.12.002. French, English. Subscription required to view.
16. Malins C, Kojdaj D, Galarza S, Chambíass, Minjares R, Dumitrescu E, de Jong R, Akumu J, Ruiz-Stannah V, Fabian B. Cleaning up the global on-road diesel fleet: a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles [Internet]. Paris, France: Climate & Clean Air Coalition; 2016 Aug [cited 2020 Jul 8]. 79 p. Available from: https://ccacoalition.org/en/resources/global-strategy-introduce%20low-sulfur-fuels-and-cleaner-diesel-vehicles.
17. Global transport scenarios 2050 [Internet]. London: World Energy Council; 2011 [cited 2020 Jul 8]. 76 p. Available from: wec-fence.org/DocumentsPDF/Etudes_CME/wec_transport_scenarios_2050.pdf
18. Banning Europe’s ‘dirty’ fuels, West African countries put people’s health first – UN environment wing. UN News [Internet]. 2016 Dec 5 [cited 2020 May 29]. Available from: https://news.un.org/en/story/2016/12/546982. Banning-europes-dirty-fuels-west-african-countries-put-peoples-health-first-un
19. Nammaghe H. La mauvaise qualité de carburants, une autre source de pollution [The
poor quality of fuels, another source of pollution. Vert Togo [Internet]. 2018 Jun 20 [cited 2020 May 29];Environment:[about 4 screens]. Available from: https://vert-togo.com/la-mauvaise-qualite-de-carburants-une-autre-source-de-pollution/ French.

20. Yadav P, Gaurav RK, Jharnavi B, Ram GD. Prediction of PM, SO₂, & NOX - GLC’s from point source emissions using air modeling. Int J Sci Eng Res [Internet]. 2013 May [cited 2020 Jul 8];4(5):5-9. Available from: https://www.ijsr.org/researchpaper/Prediction-of-PM-SO2-NOX-GLC-S-from-Point-Source-Emissions-Using-Air-Modeling.pdf

21. Gibson MD, Kundu S, Satish M. Dispersion model evaluation of PM₄, NOₓ and SO₂ from point and major line sources in Nova Scotia, Canada using AERMOD Gaussian plume air dispersion model. Atmos Poll Res [Internet]. 2013 Apr [cited 2020 Jul 8];4(2):157-67. Available from: https://doi.org/10.5094/APR.2013.016

22. Amaotepe P, Omidivarborna H, Baawain M. The modeling and health risk assessment of PM₄, from Tema Oil Refinery. Hum Ecol Risk Assess Int J [Internet]. 2018 [cited 2020 Jul 8];24(5):1181-96. Available from: https://doi.org/10.1080/10807039.2017.1410427 Subscription required to view.

23. Lee J, Vaughan A, Nelson B, Young S, Evans M, Morris E, Laddkin R. Measurement of air pollutant emissions from Lome, Cotonou and Accra [Internet]. European Geosciences Union General Assembly 2017; 2017 Apr 23-28; Vienna, Austria. Göttingen, Germany: Geophysical Research Abstracts; 2017 [cited 2020 Jul 8]. 1 p. (EGU2017-5354; vol. 19) Available from: https://meetingorganizer.copernicus.org/EGU2017/EGU2017-5354.pdf

24. Abdoun A. Fuel quality and emission standard developments in Africa [Internet]. Africa Clean Mobility Week 2018; 2018 Mar 12-16; Nairobi, Kenya. Houston (TX): Stratas Advisors; c2018 [cited 2020 Jul 8]. 20 p. Available from: https://www.ijser.org/researchpaper/FuelQualityEmissionStandardDevelopments.pdf?sequence=3&isAllowed=y

25. Cimorelli AJ, Perry SG, Venkatram A, Weil JC, Paine RJ, Wilson RB, Lee RF, Peters WD, Paumier JO. AERMOD: description of model formulation. Washington, DC: US Environmental Protection Agency; 2003. 85 p. Report No.: EPA 454/R-03-002d.

26. Cimorelli AJ, Perry SG, Venkatram A, Weil JC, Paine RJ, Wilson RB, Lee RF, Peters WD, Brode RW. AERMOD: a dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization. J Appl Meteor Climatol [Internet]. 2005 May [cited 2020 Jul 8];44(5):682-93. Available from: https://doi.org/10.1175/JAM2227.1

27. Historique-Meteo [Internet]. Saint-Grégoire, France: Des Clics Nomades; c2014 [updated 2020; cited 2020 Jul 8]. Available from:WWW. HISTORIQUE-METEO.FRENCH French.

28. Ntziachristos I, Samaras Z. EMEP/EEA air pollutant emission inventory guidebook 2016: passenger cars light commercial trucks heavy-duty vehicles including buses mopeds and motor cycles. Copenhagen, Denmark: European Environment Agency; 2018 Jul. 143 p.

29. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment [Internet]. Geneva: World Health Organization; 2006 [cited 2020 Jul 8]. 20 p. Available from: https://apps.who.int/iris/handle/10665/69477

30. Bahino J, Yoboue V, Galy-Lacaux C, Adon M, Akpo A, Keita S, Lioussse G, Gardrat E, Chiron C, Ossohou M, Gnamien S, Djoussou J. A pilot study of gaseous pollutants’ measurement (NOₓ, SO₂, NH₃, HNO₃, and O₃) in Abidjan, Côte d’Ivoire: contribution to an overview of gaseous pollution in African cities. Atmos Chem Phys [Internet]. 2018 [cited 2020 Jul 8];18:5173-98. Available from: https://doi.org/10.5194/acp-18-5173-2018

31. Mama D, Dimon B, Aina M, Adounkpe J, Ahomadegbe M, Youssoua A, Kouazounde, J Kouanda SP, Moudachiro M. Transport urbain au Benin et pollution atmosphérique: évaluation quantitative de certains polluants chimiques de Cotonou. Int J Biol Chem Sci [Internet]. 2013 [cited 2020 Jul 8];7(1):377-86. Available from: http://doi.org/10.4314/ijbcs.v7i1.33 French.

32. Adon M, Yoboue V, Galy-Lacaux C, Lioussse G, Diop B, Doumbia EH, Gardrat E, Ndiaye SA, Jarnot C. Measurements of NOₓ, SO₂, NH₃, HNO₃, and O₃ in West African urban environments. Atmos Environ [Internet]. 2016 Jun [cited 2020 Jul 8];135:31-40. Available from: https://doi.org/10.1016/j.atmosenv.2016.03.050

33. Inchaouh M, Tahiri S, El Johra B, Abboubi R. State of ambient air quality in Marrakech city (Morocco) over the period 2009 - 2012. Int J GEOMATE. 2017 Jan;12(29):99-106.

34. Khich H, Cherif S. Distribution spatiale des O₂, NOₓ et SO₂ et évaluation des interactions troposphériques sur la ville de Tunis (Tunisie) (Spacial distribution of O₂, NOₓ and SO₂ and evaluation of tropospheric interactions in Tunis (Tunisie)). Pollut Atmos [Internet]. 2015 Apr-Jun [cited 2020 Jul 8];225[11 p]. Available from: https://doi.org/10.4267/pollut-atmospherique.4814 French.

35. Val S, Lioussse C, Doumbia el HT, Galy-Lacaux C, Cachier H, Marchand N, Badel A, Gardrat E, Sylvester A, Baeza-Squiban A. Physico-chemical characterization of African urban aerosols (Bamako in Mali and Dakar in Senegal) and their toxic effects in human bronchial epithelial cells: description of a worrying situation. Part Fibre Toxicol [Internet]. 2013 Apr 2 [cited 2020 Jul 8];10:Article 10 [16 p]. Available from: https://doi.org/10.1186/1743-8977-10-10