Scientific Research Publishing

Journal of Environmental Protection, 2020, 11, 753-765
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

The Health Cost of Ambient Air Pollution in Lagos

Lelia Croitoru[1*], Jiyoun Christina Chang[1], Joseph Akpokodje[2]

[1]The World Bank Group, Washington DC, USA
[2]The World Bank Group, Abuja, Nigeria
Email: *lcroitoru@worldbank.org

How to cite this paper: Croitoru, L., Chang, J.C. and Akpokodje, J. (2020) The Health Cost of Ambient Air Pollution in Lagos. *Journal of Environmental Protection*, **11**, 753-765.
https://doi.org/10.4236/jep.2020.119046

Received: August 3, 2020
Accepted: September 19, 2020
Published: September 22, 2020

Abstract

Globally, air pollution is a significant cause of death, illness and social discomfort. The problem is particularly severe in Nigeria, the country with the highest number of premature deaths due to ambient particulate matter pollution in Sub Saharan Africa. It is especially worrying in Lagos, the country's commercial capital and one of the world's fastest growing megacities. Despite growing concerns about its deadly impacts, there is currently no reliable monetary estimate of the effects of ambient air pollution, nor a comprehensive control plan in Lagos. Using available ground-level monitored data and the most recent valuation techniques, this paper estimates that in 2018 alone, ambient fine particulate matter ($PM_{2.5}$) caused about 11,200 premature deaths, and generated a health cost of US$2.1 billion in Lagos. This is equivalent to about 2.1 percent of Lagos' GDP in the same year. These results call for an urgent plan of action to improve air quality in the city, with primary focus on the main pollution sources: road transport, industrial emissions, and power generation.

Keywords

Ambient Air Pollution, Valuation, Health Cost

1. Introduction

Ambient air pollution is a growing public health problem. The air pollutants with the strongest evidence of health effects are particulate matter, ozone, nitrogen dioxide, and sulfur dioxide [1]. Among these, fine particulate matter (particulate matter with aerodynamic diameter of less than 2.5 micrometers, or $PM_{2.5}$) is the most relevant indicator for urban air quality [2] and a well-known risk factor to health. It can pass the barriers of the lung, enter the blood stream, and destroy the integrity of the blood-brain barrier, thus causing premature deaths, as well as respiratory, cardiovascular and neurological diseases [3] [4] [5] [6].

Globally, ambient $PM_{2.5}$ pollution caused 2.9 million premature deaths, or about 9 percent of total global deaths in 2017 [7]. In the Sub Saharan Africa, it was responsible for about 150,800 premature deaths in the same year. The problem is particularly acute in Nigeria, the country with the *highest number of premature deaths* in the region due to ambient $PM_{2.5}$ pollution (49,100). Overall, the rate of premature mortality due to ambient $PM_{2.5}$ pollution in Nigeria is well above the Sub Saharan average (23.8 vs. 14.7 per 100,000 people) [8].

Lagos is the commercial and economic hub of Nigeria [9]. It is also one of the fastest growing megacities, expected to become the world's most populated city by 2100 [10]. However, fast urbanization and industrialization have exposed the majority of its population to high levels of air pollution, leading to negative impacts on health [11] [12]. Moreover, the ongoing coronavirus (COVID-19) pandemic is affecting air pollution in different ways: while the lockdown is triggering lower vehicular traffic and industrial emissions in the city [13], it likely increases the use of diesel and petrol generators by households [14].

Despite growing concerns about the air pollution challenge in Lagos, there is currently no reliable estimate of the impacts of the ambient air pollution in the city. This paper addresses this gap by providing a brief overview of the ambient $PM_{2.5}$ pollution and an economic valuation of its effects on health in Lagos. The valuation refers to the year 2018, hence it does not analyze the potential linkages among the current pandemic, air pollution and health. It is based on a study conducted in the context of the World Bank's Pollution Management and Environmental Health/Air Quality Management (PMEH/AQM) project in Lagos.

2. Ambient $PM_{2.5}$ Pollution in Lagos

Analysis of ambient $PM_{2.5}$ pollution. The climate in Nigeria has pronounced wet and dry seasons. This causes differences in pollutant dispersion and deposition, which lead to seasonal variations in ambient $PM_{2.5}$ concentration [15]. Thus, estimating the average annual $PM_{2.5}$ concentration in Lagos should be based on concentration data collected systematically throughout an entire year, at representative locations in the city. However, at the time of writing, there are no operational air quality monitoring stations in Lagos; thus, the available $PM_{2.5}$ data are primarily based on short-term and irregular measurements, using air samplers.

Worldwide, data derived from ground monitors are preferred for analysis, however their spatial coverage is usually limited. To overcome this problem, many efforts have been devoted to measuring $PM_{2.5}$ concentration using other methods, e.g. satellite-based imagery and atmospheric chemical models. However, these methods cannot fully replace surface ground-monitored data, but rather complement them [16]. Integrating data from ground-based monitors, satellite imagery, and other models should be used to fully leverage the benefits of each data source, thus providing $PM_{2.5}$ concentration estimates over a wide scale with better accuracy [17]. This type of research has not yet been conducted for Lagos.

A comprehensive review of the most recent available literature indicates a variety of results of ambient $PM_{2.5}$ concentration in Lagos. **Figure 1** shows that the $PM_{2.5}$ concentration varies from 12 μg/m^3 to 85 μg/m^3, depending on the location, season, time frame and year of measurement. One publication used satellite data, however without calibration with ground-level measurements [18]. Most other efforts collected $PM_{2.5}$ data using air samplers over short periods of time, usually less than three months [19] [20] [21] [22] [23]. Due to their short-term nature, these efforts cannot be used to compute the average annual $PM_{2.5}$ concentration in Lagos. Only two studies provide data monitored over relatively long periods of time: twice every fortnight for nine months, in four locations, from February to October 2010, by [24]; and two days a week for one year, from December 2010 to November 2011, in three locations, by [25]. As the latter monitored $PM_{2.5}$ concentration more frequently over a longer period of time, we use their results[1] to estimate the population-weighted $PM_{2.5}$ concentration for Lagos city. As explained in the next section, this is estimated at 68 μg/m^3.

The above estimate can be considered conservative, given that: 1) it is based on data monitored during 2010-2011; 2) ever since, economic development and traffic growth have most likely increased even more the atmospheric pollution. Despite being conservative, the estimate exceeds by far the guideline value set by the World Health Organization (WHO) of 10 μg/m^3 [1]. Interestingly, it is also in the same range with that of other very polluted megacities, such as Beijing and Cairo, as illustrated in **Figure 2**.

Sources of air pollution. There are multiple sources of ambient $PM_{2.5}$ pollution in Lagos. Anthropogenic sources include road transport [30], power generators [31] [32], poor waste management due to open dumpsites and illegal burning of waste [33], and construction industry [34]. In addition, natural sources, such as dust and sea salts, are also known to be significant [35].

Only a few studies on $PM_{2.5}$ source apportionment based on long-term monitoring are available for Lagos. An early study conducted by Lagos Metropolitan Area Transport Authority (LAMATA) in 2007 using positive matrix factorization analysis indicated that road transport was the major cause of pollution, accounting for 43 percent of total PM [36] [37]. Owoade *et al.* conducted principal component factor analysis in 2010. The authors found that vehicular traffic was the major contributor to $PM_{2.5}$ concentration in three locations representative of

[1]These include the $PM_{2.5}$ concentration measured in three different locations: Ikeja (77 μg/m^3; industrial area), Mushin (85 μg/m^3; high density residential area), and Ikoyi (41 μg/m^3; low density residential area).

[2]WHO also specifies that no threshold has been identified below which no damage to health is observed, and therefore, recommends to aim at achieving the lowest concentration of PM possible [1]. In addition, the GBD 2017 Risk Factor Collaborators identify the theoretical minimum risk exposure level between 2.4 μg/m^3 and 5.9 μg/m^3 for both household and ambient $PM_{2.5}$ [7].

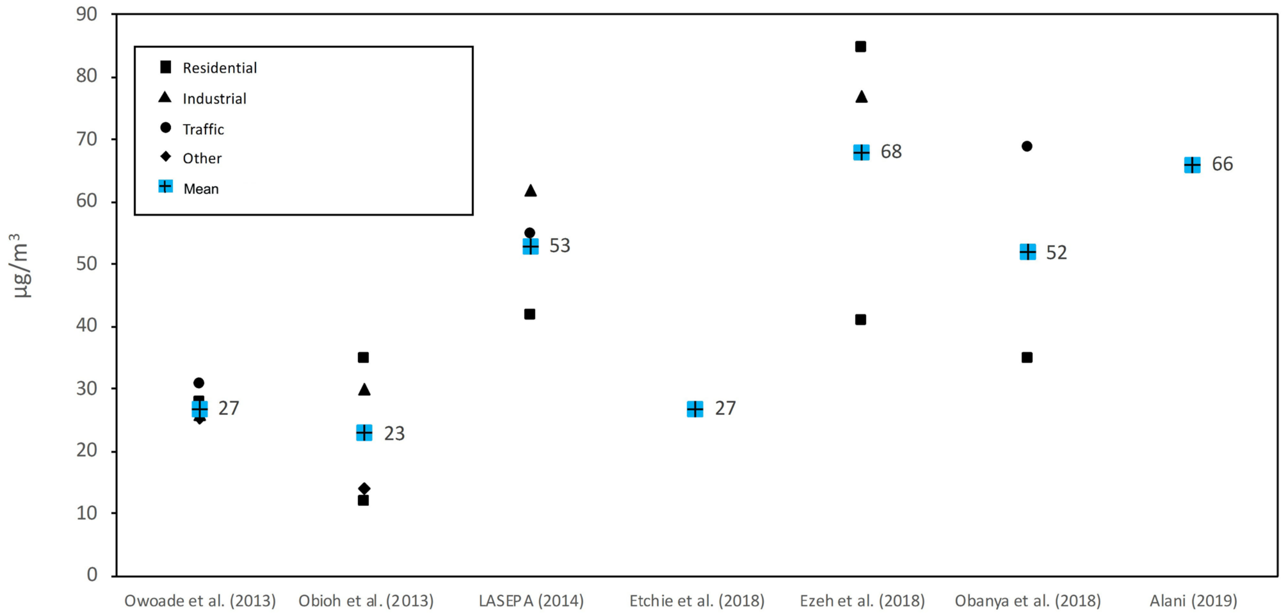

Figure 1. Ambient $PM_{2.5}$ concentration in Lagos measured by several studies. Sources: Based on [18] [19] [20] [21] [24] [25] [26] [27]. Notes: The data from Etchie *et al.* [18] reflect satellite level information, while the rest are ground level measurements. The figure reports only the results of studies that monitored $PM_{2.5}$ concentration for more than one month. The mean values represent population-weighted average for Ezeh *et al.* (2018), and arithmetic means for the other studies.

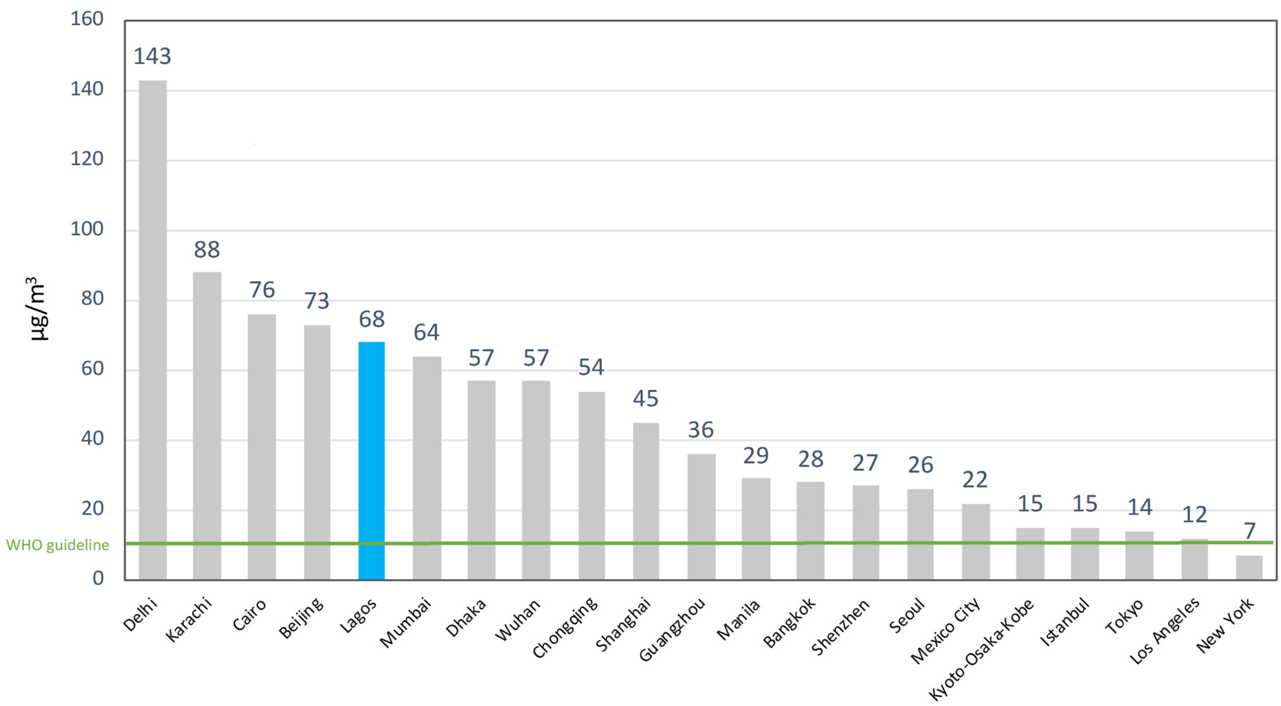

Figure 2. Annual mean $PM_{2.5}$ concentration in different megacities. Sources: [27] for Lagos; [28] [29] for other cities.

residential, heavy traffic and marine areas; while industry, followed by traffic, was the largest contributor in an industrial area [24]. Finally, Ezeh *et al.* conducted positive matrix factorization analysis using $PM_{2.5}$ data collected during 2010-2011 at three locations representative of low density residential zones, high density residential zones and industrial areas [25]. The authors concluded that petroleum combustion stemming from vehicular traffic and petrol-driven electric generators accounted for 70 percent of the overall $PM_{2.5}$ mass load.

Overall, these results suggest that ***road transport*, *industrial emissions and power generation*** are the largest contributors to ambient $PM_{2.5}$ pollution in Lagos. Moreover, a recent analysis of the transport situation in Lagos suggests that road transport is a key source of air pollution in the city. This is primarily due to high vehicle density (227 vehicles/km/day), use of old emission technologies (most cars are more than 15 years old), high sulfur content in imported fuel (3000 ppm in diesel and 1000 in gasoline), and limited transportation options in the city (only 1.3 km per million people of intracity rail, far less than in other megacities) [27]. A refined source apportionment study based on long-term monitored data is needed to identify and quantify the contribution of each source to the $PM_{2.5}$ pollution in Lagos.

3. The Economic Cost of Air Pollution

Exposure to ambient $PM_{2.5}$ is responsible for premature mortality (e.g. due to respiratory and heart diseases) and morbidity (e.g. due to chronic bronchitis, and acute lower respiratory infections in children). This analysis targets only Lagos city, which population is estimated at 24.4 million people in 2018[3]. The valuation of the health cost is based on the following steps:

1) ***Selecting data on $PM_{2.5}$ concentration***. **Figure 1** illustrates results of a comprehensive review of the $PM_{2.5}$ concentration data in Lagos. As Ezeh *et al.* monitored the $PM_{2.5}$ concentration more frequently over the longest period of time (one year), we use their results to estimate the population-weighted $PM_{2.5}$ concentration in the following step [25].

2) ***Estimating the population-weighted $PM_{2.5}$ concentration***. This is conducted by using data on:

- $PM_{2.5}$ concentration measured at three monitoring stations: Ikeja (77 μg/m³), Mushin (85 μg/m³) and Ikoyi (41 μg/m³).
- Proportion of the population exposed to air pollution around each of the above monitoring stations, calculated using the Geographic Information System[4]: Ikeja (18 percent), Mushin (46 percent) and Ikoyi (36 percent).

Based on the above information, the average population-weighted $PM_{2.5}$ concentration is estimated at 68 μg/m³. Considering that most $PM_{2.5}$ monitoring efforts in Lagos have been conducted sporadically and over short periods of time, it is not possible to compare this estimate with more recent long-term

[3]Based on records derived from the 2006 population census and further projections carried out by Lagos Bureau of Statistics. The estimated population covers all Local Government Authorities, except for Bagadry (555,200 people), Epe (472,300 people) and Ibeju-Lekki (145,300 people).

[4]The estimation was conducted using the GIS, based on the following method: 1) mapping the monitoring sites, using the coordinates of the locations from GoogleMaps; 2) spatially join the population value that intersect the location of each site; 3) calculate the share of population at site versus the total population of the city; 4) derive the population exposed at each site using the share and population values.

ground-level measurements[5].

3) ***Quantifying the health impacts of exposure to $PM_{2.5}$***. An increasing body of epidemiological evidence supports strong correlations between long-term exposure to $PM_{2.5}$ and premature mortality related to: ischemic heart disease; stroke; chronic obstructive pulmonary disease; tracheal, bronchus and lung cancer; and diabetes mellitus type 2; and to lower respiratory infections in all ages [38] [39] [40]. The number of premature deaths attributable to $PM_{2.5}$ pollution is estimated using data on: 1) mortality by disease and age group, based on the Global Burden of Disease study[6]; 2) proportion of deaths due to $PM_{2.5}$ calculated by using specific relative risk factors, which are available by disease, age and $PM_{2.5}$ concentration [7].

The results show that exposure to ambient $PM_{2.5}$ is responsible for about **11,200** ***premature deaths*** in Lagos in 2018. Lower respiratory infections are the leading cause of $PM_{2.5}$-related mortality; children under five are the most affected group, accounting for about 60 percent of total deaths (**Figure 3**). This finding is consistent with the results of the Global Burden of Disease study, which found that children under five account for a similar proportion in the total ambient $PM_{2.5}$-related deaths at the national level in Nigeria. In this context, it is important to note that Nigeria's under five mortality due to lower respiratory infections (all risks combined, including air pollution) is the highest in Africa and the second highest in the world, after India[7].

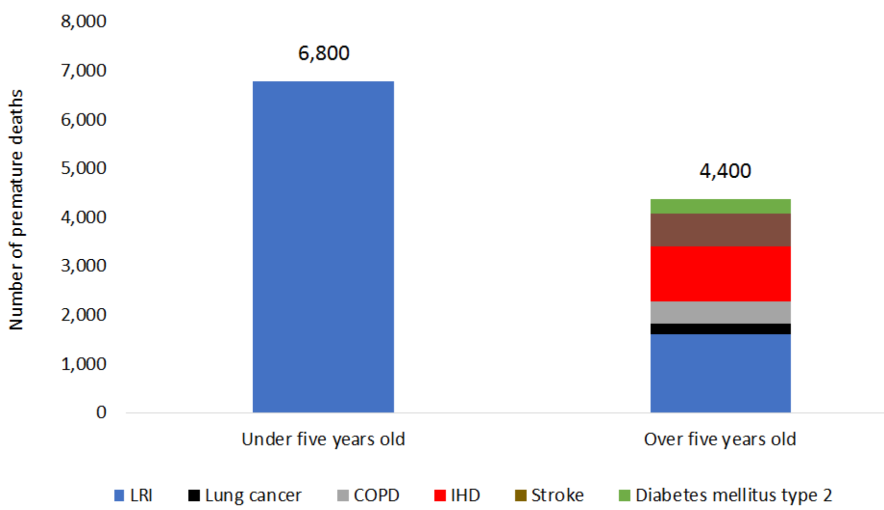

Figure 3. Estimated number of premature deaths due to ambient $PM_{2.5}$ in Lagos (2018). Source: Authors, based on [27]. Notes: COPD = chronic obstructive pulmonary diseases; IHD = ischemic heart disease; LRI = lower respiratory infections.

[5]However, data monitored at the Department of Chemistry of the University of Lagos during November 2018-March 2019 indicates an average $PM_{2.5}$ concentration of 66 μg/m³ [26]. Although a direct comparison between the two estimates is difficultc—due to the difference in the monitoring period and specific locations of the measurement—they suggest that the estimated 68 μg/m³ is a reasonable approximation of the average $PM_{2.5}$ concentration in Lagos.

[6]http://www.healthdata.org/gbd

[7]There were about 153,000 premature deaths in Nigeria due to lower respiratory infections in 2017, based on IHME [8].

4) ***Estimating the value of health impacts due to exposure to $PM_{2.5}$***. The economic cost of health is estimated as follows:

- ***Mortality***. The cost of fatality is estimated based on the number of premature deaths and the Value of Statistical Life (VSL). The latter reflects the society's willingness to pay to reduce the risk of death, in other words, the local trade-off rate between fatality risk and money [41]. The VSL for Nigeria was estimated at about US$167,400, based on benefits transfer of a base value from a meta-analysis conducted in countries of the Organisation for Economic Co-operation and Development (OECD) [27] [42]. Accordingly, the cost of mortality is appraised at *US$1.9 billion*.
- ***Morbidity***. The literature assessing causal relationships between exposure to $PM_{2.5}$ and morbidity is much more limited than that for mortality. Based on data from a few countries, several authors recommend using 10 percent of mortality cost to account for morbidity [43] [44]. This might be a significant underestimate: recent research estimated the cost of morbidity at about 66 percent of the mortality cost in China [45] and about 74 percent in Poland [46]. In the absence of studies in Nigeria, we use the most conservative assumption from the above (10 percent of the mortality cost), and the resulting morbidity cost is about *US$0.2 billion*.

Based on the above, the cost of health due to exposure to ambient $PM_{2.5}$ is estimated at **US$2.1 billion**. This corresponds to about 2.1 percent of the Lagos State' GDP[8], or 0.5 percent of the country's GDP in 2018.

4. Discussion

This is the first effort estimating the health cost of air pollution in Lagos city, based on ground-level monitored data, to the authors' knowledge. Previous studies valuing the cost of air pollution in Nigeria are also worth noting. For example, Etchie *et al.* estimated the health cost of air pollution in all Nigerian states, based on satellite-derived $PM_{2.5}$ data [18]; the result for Lagos State was substantially lower than that of the present study (US$1.1 billion vs. US$2 billion), primarily due to the use of a lower $PM_{2.5}$ concentration data and a slightly different methodology. Yaduma *et al.* estimated the economic cost of PM_{10} pollution at the national level at US$33.5 billion in 2006 [47], using an earlier methodology [48], not comparable to that employed in the present study [7].

To put these results in perspective, **Figure 4** provides estimates of $PM_{2.5}$ concentration and related impacts in other coastal cities of Africa: Dakar (Senegal), Cotonou (Benin), Lomé (Togo), Abidjan (Côte d'Ivoire) and Cairo (Egypt) [49] [50]. Among the West African cities, air pollution is particularly worrying in Lagos, the city with the highest number of $PM_{2.5}$-related deaths, both in absolute (11,200 deaths) and relative terms (46 deaths per 100,000 people). It is slightly lower than that in Cairo, a megacity with a higher level of ambient $PM_{2.5}$ concentration.

[8]Based on a GDP for Lagos State of US$98 billion in 2018, estimated by the World Bank in August 2020, based on data from the Lagos Bureau of Statistics.

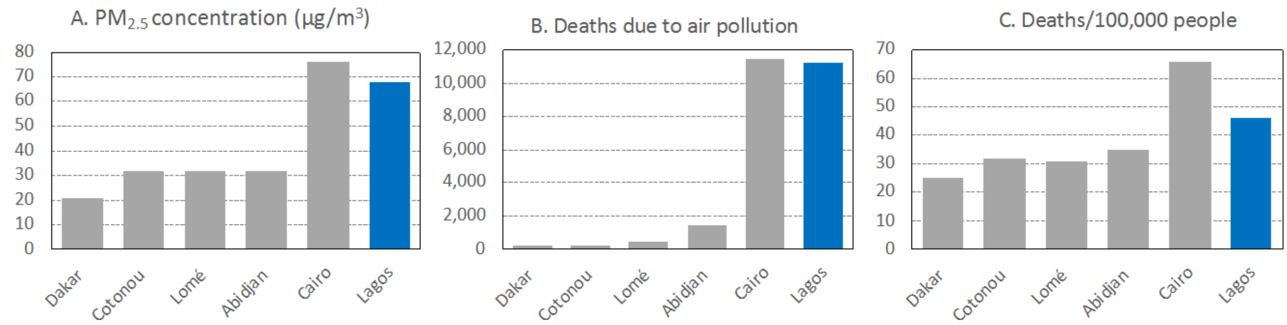

Figure 4. Ambient air pollution and impacts in selected African cities. Sources: [27] for Lagos; [50] for Cairo; [49] for other cities. A portion of these estimates represents deaths due to the joint effect of exposure to ambient and household air pollution.

The above valuation is based on the most recent available methodology for the quantification of the health impacts from air pollution, developed by the Institute for Health Metrics and Evaluation (IHME). However, it is important to note that the analysis is subject to data limitations, including the use of: ground-level $PM_{2.5}$ concentration data from 2010-2011; estimates of mortality from global statistics (IHME); and the VSL, to estimate mortality. Although the VSL concept has been commonly used [51], its application is still subject to challenges: in countries where primary surveys have been conducted, its application often generated a wide variety of results, depending on the approach used, type of survey, etc.; in countries with no primary surveys, the VSL has been usually obtained through benefits transfer of a value from a different country. The latter is the case of the present study, where the VSL has been derived through benefits transfer of a base value from OECD countries, following the World Bank guidelines [44].

5. Conclusions

This paper demonstrates that exposure to ambient $PM_{2.5}$ has a very large health impact on Lagos' society. In 2018, it was responsible for about 11,200 premature deaths, with a health cost of US$2.1 billion, or 2.1 percent of Lagos State' GDP. Road transport, industrial activity, and power generation are the most important sources of ambient $PM_{2.5}$ pollution. These results call for urgent actions to address air pollution in Lagos. Several options should be investigated, e.g. incentives for purchasing cleaner passenger vehicles, vehicle inspections, retrofitting the most polluting vehicles, adoption of cleaner fuel, use of solar cells with battery storage for power generation [27]. It is clear that no single action can solve the air pollution challenges faced by the city. An evidence-based air pollution control plan that considers interventions across the most polluting sectors is required and envisaged by the World Bank's PMEH/AQM project in Lagos.

Finally, it is important to note that this study is based on a comprehensive review of existing air quality data, health information and the local context in Lagos. However, available information in these areas was often limited. To refine these results, priority areas for future work include: conduct long-term monitoring of ambient $PM_{2.5}$ in several representative locations of major activities in the city, e.g. transport, industry, landfills; undertake refined source apportionment studies that quantify and localize the contribution to the $PM_{2.5}$ pollution in the city; develop an inventory of air pollutant emissions in Lagos, including particulate matter, nitrogen dioxide, and sulfur dioxide; centralize health-related information data (e.g. mortality and morbidity by cause and age) at the state level, and examine the impact of household air pollution on health in Lagos[9].

Acknowledgements

This paper is based on a comprehensive study which addressed the air pollution sources, costs and policy options in Lagos. The authors gratefully acknowledge the financial support provided to the original study by the World Bank's Pollution Management and Environmental Health/Air Quality Management (PMEH/AQM) project in Lagos. Special thanks are given to Mr. Andrew Kelly, Ms. Abimbola Adeboboye, Dr. Rose Alani, Mr. Iguniwari Ekeu-Wei, Mr. Jia Jun Lee, Mr. John Allen Rogers, Ms. Maria Sarraf, and Mr. Sanjay Srivastava for their support.

The authors would like to acknowledge the valuable inputs provided to the original study by Mr. Tayo Oseni-Ope (Director), Mr. Peter Kehinde Olowu (Deputy Director), and Mrs. Bolanle Pemede (Assistant Director) at the Lagos State Ministry of Economic Planning and Budget/Lagos Bureau of Statistics; Dr. Idowu Abiola (Director, Lagos Health Management Information System) and Dr. Kuburat Enitan Layeni-Adeyemo (Director, Occupational Health Services) at Lagos State Ministry of Health; Dr. Frederic Oladeinde (Director, Corporate and Investment Planning Department), Mr. Obafemi Shitta-Bey (Deputy Director, Corporate and Investment Planning Department) and Mr. Ayodipupo Quadri (Environment and Safety Specialist) at Lagos Metropolitan Area Transport Authority; Mr. Lewis Gregory Adeyemi (Chief Scientific Officer) at the Lagos State Ministry of Environment/Lagos State Environmental Protection Agency; and Mr. Adedotun Atobasire (Deputy Director, Census) at the National Population Commission; and Mr. Emmanuel Ojo (Former Focal Point and Deputy Director, Pollution Control and Environmental Health Department) at the Federal Ministry of Environment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] World Health Organization (WHO) (2006) WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005.

[9]Such a study could build on [52], which estimated the health impacts of household and ambient air pollution on the coastal zone of Lagos, Cross River and Delta. Conducting systematic monitoring of $PM_{2.5}$ in different types of households would help refine those estimates.

[2] Cohen, A.J., Anderson, H.R., Ostro, B., Pandey, K.D., Krzyzanowski, M., Künzli, N., *et al.* (2005) The Global Burden of Disease Due to Outdoor Air Pollution. *Journal of Toxicology and Environmental Health*, *Part A*, **68**, 1301-1307. https://doi.org/10.1080/15287390590936166

[3] Brook, R.D., Rajagopalan, S., Pope, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., *et al.* (2010) Particulate Matter Air Pollution and Cardiovascular Disease. *Circulation*, **121**, 2331-2378. https://doi.org/10.1161/CIR.0b013e3181dbece1

[4] Bowe, B., Xie, Y., Yan, Y. and Al-Aly, Z. (2019) Burden of Cause-Specific Mortality Associated with PM2.5 Air Pollution in the United States. *JAMA Network Open*, **2**, e1915834. https://doi.org/10.1001/jamanetworkopen.2019.15834

[5] Shou, Y., Huang, Y., Zhu, X., Liu, C., Hu, Y. and Wang, H. (2019) A Review of the Possible Associations between Ambient PM2.5 Exposures and the Development of Alzheimer's Disease. *Ecotoxicology and Environmental Safety*, **174**, 344-352. https://doi.org/10.1016/j.ecoenv.2019.02.086

[6] Peeples, L. (2020) News Feature: How Air Pollution Threatens Brain Health. *Proceedings of the National Academy of Sciences*, **117**, 13856-13860. https://doi.org/10.1073/pnas.2008940117

[7] GBD 2017 Risk Factor Collaborators (2018) Global, Regional, and National Comparative Risk Assessment of 84 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks for 195 Countries and Territories, 1990-2017: A Systematic Analysis for the Global Burden of Disease Stu. *The Lancet*, **392**, 1923-1994.

[8] Institute for Health Metrics and Evaluation (IHME), Global Burden Disease (GBD) Compare. https://vizhub.healthdata.org/gbd-compare/

[9] Lagos State Government. About Lagos. https://lagosstate.gov.ng/about-lagos/

[10] Hoornweg, D. and Pope, K. (2016) Population Predictions for the World's Largest Cities in the 21st Century. *Environment and Urbanization*, **29**, 195-216. https://doi.org/10.1177/0956247816663557

[11] Olowoporoku, A.O., Longhurst, J.W.S. and Barnes, J.H. (2012) Framing Air Pollution as a Major Health Risk in Lagos, Nigeria. *WIT Transactions on Ecology and the Environment*, **157**, 479-488. https://doi.org/10.2495/AIR120421

[12] Orisaleye, J., Ope, A., Busari, O. and Adefuye, O. (2018) Environmental and Health Effects of Industrial and Vehicular Emissions in Lagos, Nigeria. *International Journal of Engineering*, **16**, 225-230.

[13] Mogaji, E. (2020) Impact of COVID-19 on Transportation in Lagos, Nigeria. *Transportation Research Interdisciplinary Perspectives*, **6**, Article ID: 100154. https://doi.org/10.1016/j.trip.2020.100154

[14] Kazeem, Y. (2020) The Coronavirus Lockdown in Africa's Largest City Opens the Door to Increased Generator Pollution. QUARTZ AFRICA. https://qz.com/africa/1829142/coronavirus-lockdown-in-nigeria-will-worsen-generator-pollution

[15] Petkova, E.P., Jack, D.W., Volavka-Close, N.H. and Kinney, P.L. (2013) Particulate Matter Pollution in African Cities. *Air Quality*, *Atmosphere and Health*, **6**, 603-614. https://doi.org/10.1007/s11869-013-0199-6

[16] Duncan, B.N., Prados, A.I., Lamsal, L.N., Liu, Y., Streets, D.G., Gupta, P., *et al.* (2014) Satellite Data of Atmospheric Pollution for U.S. Air Quality Applications: Examples of Applications, Summary of Data End-User Resources, Answers to FAQs, and Common Mistakes to Avoid. *Atmospheric Environment*, **94**, 647-662. https://doi.org/10.1016/j.atmosenv.2014.05.061

[17] Diao, M., Holloway, T., Choi, S., O'Neill, S.M., Al-Hamdan, M.Z., Van Donkelaar, A., *et al.* (2019) Methods, Availability, and Applications of PM2.5 Exposure Estimates Derived from Ground Measurements, Satellite, and Atmospheric Models. *Journal of the Air & Waste Management Association*, **69**, 1391-1414. https://doi.org/10.1080/10962247.2019.1668498

[18] Etchie, T.O., Etchie, A.T., Adewuyi, G.O., Pillarisetti, A., Sivanesan, S., Krishnamurthi, K., *et al.* (2018) The Gains in Life Expectancy by Ambient PM2.5 Pollution Reductions in Localities in Nigeria. *Environmental Pollution*, **236**, 146-157. https://doi.org/10.1016/j.envpol.2018.01.034

[19] Obioh, I.B., Ezeh, G.C., Abiye, O.E., Alpha, A., Ojo, E.O. and Ganiyu, A.K. (2013) Atmospheric Particulate Matter in Nigerian Megacities. *Toxicological and Environmental Chemistry*, **95**, 379-385. https://doi.org/10.1080/02772248.2013.790970

[20] LASEPA (2014) Air Pollution and Particulate Matter. Study Results.

[21] Obanya, H.E., Nnamdi, H. and Togunde, O. (2018) Air Pollution Monitoring around Residential and Transportation Sector Locations in Lagos Mainland. *Journal of Health & Pollution*, **8**, 1-10. https://doi.org/10.5696/2156-9614-8.19.180903

[22] uMoya Nilu Consulting (2016) Fact-Finding Air Quality Monitoring Mission Report. Lagos. December 11-18, 2015.

[23] Alani, R.A., Ayejuyo, O.O., Akinrinade, O.E., Badmus, G.O., Festus, C.J., Ogunnaike, B.A., *et al.* (2019) The Level PM2.5 and the Elemental Compositions of Some Potential Receptor Locations in Lagos, Nigeria. *Air Quality*, *Atmosphere & Health*, **12**, 1251-1258. https://doi.org/10.1007/s11869-019-00743-3

[24] Owoade, O.K., Fawole, O.G., Olise, F.S., Ogundele, L.T., Olaniyi, H.B., Almeida, M.S., *et al.* (2013) Characterization and Source Identification of Airborne Particulate Loadings at Receptor Site-Classes of Lagos Mega-City, Nigeria. *Journal of the Air and Waste Management Association*, **63**, 1026-1035. https://doi.org/10.1080/10962247.2013.793627

[25] Ezeh, G.C., Obioh, I.B., Asubiojo, O.I., Onwudiegwu, C.A., Nuviadenu, C.K. and Ayinla, S.B. (2018) Airborne Fine Particulate Matter (PM2.5) at Industrial, High- and Low-Density Residential Sites in a Nigerian Megacity. *Toxicological & Environmental Chemistry*, **100**, 326-333. https://doi.org/10.1080/02772248.2018.1485924

[26] Alani, R. (2019) PM2.5 Data Measured during November 2018-March 2019 (Unpublished, Communication with the World Bank).

[27] Croitoru, L., Chang, J.C. and Kelly, A. (2020) The Cost of Air Pollution in Lagos. The World Bank, Washington DC. https://doi.org/10.1596/33038

[28] World Health Organization (WHO) (2016) Ambient (Outdoor) Air Pollution Database. https://www.who.int/airpollution/data/cities-2016/en

[29] World Health Organization (WHO) (2018) Global Ambient Air Quality Database. https://www.who.int/airpollution/data/en

[30] Ibitayo, O.O. (2012) Towards Effective Urban Transportation System in Lagos, Nigeria: Commuters' Opinions and Experiences. *Transport Policy*, **24**, 141-147. https://doi.org/10.1016/j.tranpol.2012.07.009

[31] Oseni, M.O. (2016) Get Rid of It: To What Extent Might Improved Reliability Reduce Self-Generation in Nigeria? *Energy Policy*, **93**, 246-254. https://doi.org/10.1016/j.enpol.2016.03.013

[32] Cervigni, R., Rogers, J.A. and Dvorak, I. (2013) Assessing Low-Carbon Development in Nigeria: An Analysis of Four Sectors. World Bank, Washington DC.

https://doi.org/10.1596/978-0-8213-9973-6

[33] Adegboye, K. (2018) Why Problem of Waste Management Persists in Lagos. Vanguard. https://www.vanguardngr.com/2018/10/why-problem-of-waste-management-persists-in-lagos-stakeholders

[34] Adama, O. (2018) Urban Imaginaries: Funding Mega Infrastructure Projects in Lagos, Nigeria. *GeoJournal*, **83**, 257-274. https://doi.org/10.1007/s10708-016-9761-8

[35] Marais, E.A., Silvern, R.F., Vodonos, A., Dupin, E., Bockarie, A.S., Mickley, L.J., *et al.* (2019) Air Quality and Health Impact of Future Fossil Fuel Use for Electricity Generation and Transport in Africa. *Environmental Science & Technology*, **53**, 13524-13534. https://doi.org/10.1021/acs.est.9b04958

[36] LAMATA (2008) Lagos Vehicular Emission (Air Quality) Monitoring Study.

[37] LAMATA (2016) Data Gathering to Implement GHG Emissions Reduction Assessment Methodology for LUTP II BRT Corridors.

[38] Apte, J.S., Marshall, J.D., Cohen, A.J. and Brauer, M. (2015) Addressing Global Mortality from Ambient PM2.5. *Environmental Science and Technology*, **49**, 8057-8066. https://doi.org/10.1021/acs.est.5b01236

[39] Soriano, J.B., Kendrick, P.J., Paulson, K.R., Gupta, V., Abrams, E.M., Adedoyin, R.A., *et al.* (2020) Prevalence and Attributable Health Burden of Chronic Respiratory Diseases, 1990-2017: A Systematic Analysis for the Global Burden of Disease Study 2017. *The Lancet Respiratory Medicine*, **8**, 585-596. https://doi.org/10.1016/S2213-2600(20)30105-3

[40] Wu, X., Braun, D., Schwartz, J., Kioumourtzoglou, M.A. and Dominici, F. (2020) Evaluating the Impact of Long-Term Exposure to Fine Particulate Matter on Mortality among the Elderly. *Science Advances*, **6**, eaba5692. https://doi.org/10.1126/sciadv.aba5692

[41] Kniesner, T. and Viscusi, W.K. (2019) The Value of Statistical Life. Vanderbilt Law Research Paper No. 19-15. https://doi.org/10.2139/ssrn.3379967

[42] Narain, U. and Sall, C. (2016) Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions. International Bank for Reconstruction and Development/The World Bank, Washington DC. https://doi.org/10.1596/24440

[43] Hunt, A., Ferguson, J., Hurley, F. and Searl, A. (2016) Social Costs of Morbidity Impacts of Air Pollution. OECD Publishing, Paris.

[44] World Bank and Institute for Health Metrics and Evaluation (2016) The Cost of Air Pollution. World Bank, Washington DC.

[45] Barwick, P.J., Li, S., Rao, D. and Zahur, N.B. (2018) The Morbidity Cost of Air Pollution: Evidence from Consumer Spending in China. National Bureau of Economic Research, 24688. https://doi.org/10.3386/w24688

[46] Ligus, M. (2018) Measuring the Willingness to Pay for Improved Air Quality: A Contingent Valuation Survey. *Polish Journal of Environmental Studies*, **27**, 763-771. https://doi.org/10.15244/pjoes/76406

[47] Yaduma, N., Kortelainen, M. and Wossink, A. (2013) Estimating Mortality and Economic Costs of Particulate Air Pollution in Developing Countries: The Case of Nigeria. *Environmental and Resource Economics*, **54**, 361-387. https://doi.org/10.1007/s10640-012-9598-7

[48] Ostro, B. (1994) Estimating the Health Effects of Air Pollutants: A Method with an Application to Jakarta (English). Washington DC.

[49] Croitoru, L., Miranda, J.J. and Sarraf, M. (2019) The Cost of Coastal Zone Degradation in West Africa. The World Bank, Washington DC. https://doi.org/10.1596/31428

[50] Larsen, B. (2019) Arab Republic of Egypt—Cost of Environmental Degradation. World Bank, Washington DC. https://doi.org/10.1596/32513

[51] Viscusi, W.K. and Masterman, C.J. (2017) Income Elasticities and Global Values of a Statistical Life. *Journal of Benefit-Cost Analysis*, **8**, 226-250. https://doi.org/10.1017/bca.2017.12

[52] Croitoru, L., Miranda, J.J., Khattabi, A. and Lee, J.J. (2020) The Cost of Coastal Zone Degradation in Nigeria: Cross River, Delta and Lagos States. Washington DC.