Open Access Library Journal
2021, Volume 8, e7454
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Aviation Noise and Air Pollution: Results of a Study at Entebbe International Airport, Uganda

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How to cite this paper: Omolo, A., Angiro, C., Wagaye, W.A., Olomo, E., Okino, J. and Omara, T. (2021) Aviation Noise and Air Pollution: Results of a Study at Entebbe International Airport, Uganda. *Open Access Library Journal*, **8**: e7454.
https://doi.org/10.4236/oalib.1107454

Received: April 25, 2021
Accepted: May 25, 2021
Published: May 28, 2021

Abstract

For a landlocked country like Uganda, air transport is centermost to its import-export trade. As such, the aviation industry is important for its economic and political survival since it guarantees access to the outside world. This study reports on the noise and air pollution levels at Entebbe International Airport, Uganda. We found that the airport experiences irregular noise frequencies with the midday having the highest noise intensities that exceed permissible limits of 60 decibels. Carbon dioxide is the highest air pollutant produced at the airport probably due to anthropogenic emissions from both aviation and vehicular activities. Based on particulate matter ($PM_{2.5}$ and PM_{10}) the air quality index was less than 50, indicating that the air quality was good. Therefore, the aviation authorities need to ensure that these air pollutants are monitored and controlled continuously. The expansion of EBB alongside the development of residential areas might amplify noise and air pollution if cleaner technologies are not embraced. Further studies should perform audiogram assessments (acoustic estimation of noise-induced hearing loss) at the airport.

Subject Areas

Environmental Chemistry, Air Pollution

Keywords

Ambient Air Quality, Carbon Monoxide, Hydrogen Sulphide, Particulate

Matter, Volatile Organic Compounds

1. Introduction

Pollution is a pressing multi-sectoral challenge implicated in the progression of the decadal climate change [1]. Particularly, air and noise pollution present health, economic and social threats to countries globally [1]. There are now growing concerns by global aviation authorities and environmentalists that airports have substantial contributions to environmental pollution [2] [3] [4] [5]. They have been implicated for various ecological issues relating to acid rain, climate change, tropospheric ozone and potential risks linked to regional, ecological, environmental and public health [6]. For example, aircraft emissions of pollutants such as carbon dioxide, sulphur dioxide and volatile organic compounds are known to contribute to the atmospheric pool of greenhouse gases [3]. Aircraft air pollutant emissions are grossly categorized into 1) emissions during the landing and take-off (LTO) cycle and 2) those during the non-LTO flight cycle [3]. The former produce emissions with prominent impacts compared with the latter [7] [8] [9]. Increase in air transport volumes and expansion of airports to meet future capacity needs have made aircraft emissions during the LTO more prominent and of general research interest [4] [10] [11] [12].

Previous advances to establish air quality in Uganda and East Africa at large have been impeded by inadequate regulatory grade equipment required to record long term data and track vacillations in air pollution both temporally and spatially, as well as assess their influences on public health [1] [13] [14]. This is primarily due to the prohibitive cost of air quality monitoring equipment, and the difficulty in obtaining appropriate calibration and certification services [15] [16] [17]. Despite the paucity of air quality data, previous studies indicate that air pollution is an environmental concern that has undermined the development of safe, inclusive, resilient and sustainable cities [13]. A Systems Approach to Air Pollution (ASAP)-East Africa team has supplemented available long-term air quality monitoring with spot measurement campaigns at selected sites including outdoor and indoor locations in Uganda [14].

On the other hand, aircrafts contribute to noise pollution particularly during take-off and landing [18]. Ideally, airports should be away from human habitation so that people are not affected by the noise caused by the air traffic [19]. However, this is not the case in many countries, where human habitation is in close proximity to airports [20]. People who live away from airports but under the flight path may also get disturbed by high noise levels [21]. Noise arising from aviation activities has been implicated in the etiology and aggravation of cardiovascular diseases, hypertension, psychological ill-health, lowering of cognitive ability in children, annoyance and sleep disturbances [22] [23]. In the current study, we report on the concentration of some priority air pollutants and noise pollution levels at Entebbe International Airport (EBB), Uganda.

2. Methods

2.1. Study Area

Entebbe Airport is the principal and only Ugandan international airport. It is situated approximately six kilometers Southwest of Entebbe town at coordinates 00˚02'33"N 32˚26'37"E [24]. Located on the Northern shores of Lake Victoria (**Figure 1**), the airport is more than 30 kilometers away and South West of the central business district and capital city of Uganda (Kampala) [25]. The airport is straddled by equator at latitude 00.020 North and longitude 320 East, for which reason it is described as the "Airport on the Equator" [26]. At about 3782 feet above sea level, the airport is part of a peninsular bordering Africa's biggest fresh water-Lake Victoria.

2.2. Determination of Noise Levels

Noise levels were determined using a Castle GA112 octave band sound level meter (Castle Advanced Solutions, UK). Noise levels were measured thrice daily by giving a time range of 4 hours from the initial test (*i.e.* at 8:00 am, 12:00 pm and 4:00 pm). This is because noise intensity is dispersed very easily and therefore it cannot be taken at close intervals [27].

2.3. Measurement of Air Pollutant Levels

Particulate matter with diameters less than 2.5 and 10 microns ($PM_{2.5}$ and PM_{10}, respectively) in air were measured using a BR-SMART-126 Particle Counter

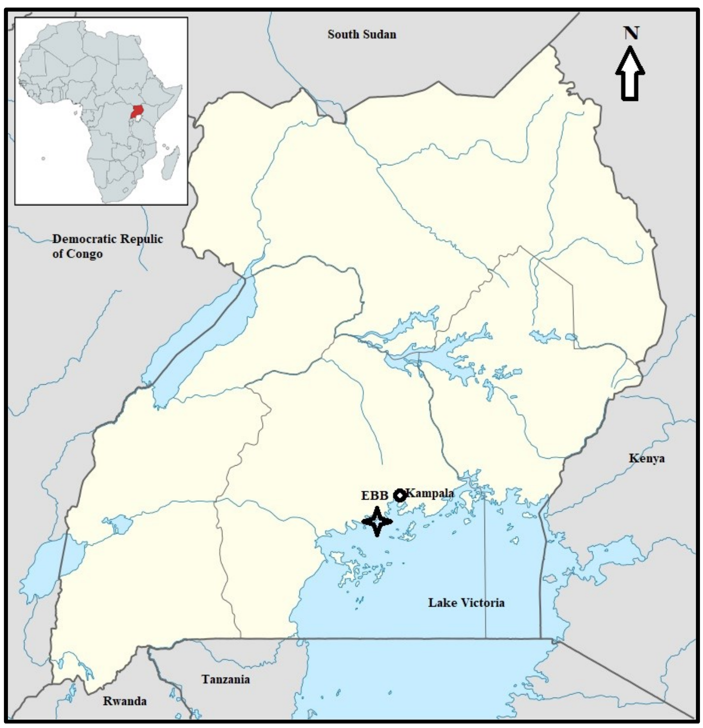

Figure 1. Map of Uganda showing the location of Entebbe International Airport. Inset is the location of Uganda on the African continent.

(Blatn Science & Technology Co. Ltd., Beijing, China) [28]. Aeroqual S500L portable air quality monitor (Aeroqual Limited, Auckland, New Zealand) was used for measuring carbon dioxide, carbon monoxide, hydrogen sulphide, sulphur dioxide, ozone and volatile organic compounds (VOCs) concentration. The free Series 500 6.4 PC Software was used for data extraction from the monitor. Testing for all the air pollutant parameters was done after every 1 hour for 8 hours (8:00 am to 4:00 pm, East African Standard Time). All handheld devices employed in this study were pre-calibrated before usage for effectiveness and quality assurance purposes.

2.4. Risk Assessment

Mean values of $PM_{2.5}$ and PM_{10} were compared with the World Health Organization guidelines *i.e.* annual mean for $PM_{2.5}$ is 10 μg/m³, 24-hour mean = 25 μg/m³ while PM_{10} = 20 μg/m³ and 24-hour mean = 50 μg/m³ [29]. The mean values were harnessed to compute the air quality index (AQI). The indices for each pollutant (average of the total sum from each sampling location) were calculated using Equation (1) [30] [31] [32].

$$AQI_{pollutant} = \frac{\text{Air pollutant concentration}}{\text{WHO standard}} \times 100\% \quad (1)$$

The AQI according to United State Environmental Protection Agency (US EPA) is an index for reporting daily air quality as it indicates how clean or unhealthy the air is, the level of concern and the health effects [30] [31] [32]. The AQI focuses on "health effects an individual may experience within a few hours or days after breathing unhealthy air". **Table 1** shows the air quality index rating [33] [34] and the AQI pollutant concentration specific range for $PM_{2.5}$ and PM_{10}. Generally, lower AQI values indicate better air quality [30] [31] [32].

2.5. Data Analysis

Quantitative data were presented as means ± standard deviation of replicates. The analyses were done using GraphPad Prism statistical software (version 9.1.0, GraphPad Software, USA). Results obtained were compared with international compliance guidelines.

Table 1. Air quality index (AQI), $PM_{2.5}$ and PM_{10} concentration color codes and the air pollutant level of health concern.

AQI value of index	Level of health concern	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	Daily AQI colour	Pollution level
0 to 50	Good	0 to 12	0 to 54	GREEN	Level 1
51 to 100	Moderate	12.1 to 35.4	55 to 154	YELLOW	Level 2
101 to 150	Unhealthy for sensitive groups	35.5 to 55.4	155 to 254	ORANGE	Level 3
151 to 200	Unhealthy	55.5 to 150.4	255 to 354	RED	Level 4
201 to 300	Very unhealthy	150.5 to 250.4	355 to 424	PURPLE	Level 5
>300	Hazardous	>250.4	>424	MAROON	Level 6

3. Results and Discussion

3.1. Noise Pollution Levels

Aviation activities have become one of the causes of acoustic degradation of the environment [35] [36] [37]. **Figure 2** shows that Entebbe International Airport experiences irregular noise frequencies with the midday having the highest noise intensities. The international standards for aviation noise levels are estimated at 60 decibels (dB) for daytime (6:00 am - 10:00 pm). Therefore, the levels did not match with the International Aviation Standards for sometimes of the day. This causes discomposure at the airport especially at the terminal which is a public area all the times. However, the noise levels were also increased due to surface traffic and construction works following the current expansion of the airport. A study in Turkey reported that the rush hour for Van Ferit Melen airport is between 10:00 and 14:00 hours. The measured noise level average was 96.0 ± 8.4 dB in the apron and 86.0 ± 8.7 dB in the terminal area [27].

Previous studies linked aviation noise to sleep disturbances, hypertension, heart diseases, cognitive and learning deficits in children [38]. According to ISO standards, 0 - 26 dB hearing value is the normal hearing range, 27 - 40 dB can cause very mild hearing loss, 41 - 55 dB to mild hearing loss, 56 - 70 dB causes moderate hearing loss, 71 - 90 dB causes advanced hearing loss while 90 dB and above may cause more advanced hearing loss [39].

3.2. Air Pollutants Concentration

The levels of air pollutants determined are shown in **Table 2**. Particulate matter ($PM_{2.5}$ and PM_{10}) ranged from 3.0 to 17.0 μg/m^3 and 3.0 to 21.0 μg/m^3, respectively. This implies that the particulate matter levels at EBB were all below the World Health Organization recommended levels of $PM_{2.5}$ and PM_{10} (*i.e.* daily mass concentrations of 25 μg/m^3 and 50 μg/m^3) [40]. Particulate matter is a common proxy indicator for air pollution as it has effects on people more than

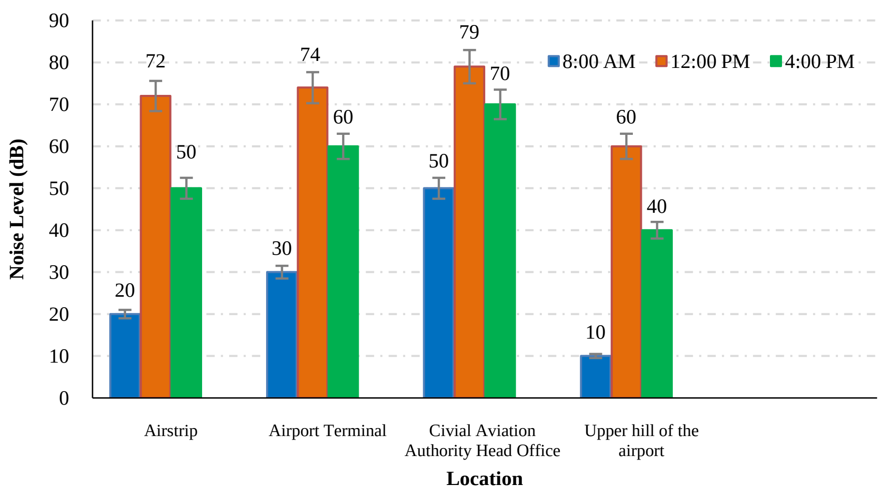

Figure 2. Noise levels at different times of the day at Entebbe International Airport, Uganda.

Table 2. Average concentration of air pollutants at Entebbe International Airport, Uganda.

Location	Time	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	VOC (μg/m³)	CO_2 (ppm)	Ozone (ppm)	CO (ppm)	H_2S (ppm)	SO_2 (ppm)
Airstrip	08:00 am	5.00 ± 0.10	6.00 ± 0.04	0.49 ± 0.01	583.00 ± 0.03	ND	3.40 ± 0.10	0.20 ± 0.01	ND
	09:00 am	7.00 ± 0.13	8.00 ± 0.10	0.42 ± 0.05	585.00 ± 0.10	ND	1.70 ± 0.01	0.10 ± 0.00	ND
	10:00 am	6.00 ± 0.05	7.00 ± 0.02	0.43 ± 0.01	580.00 ± 2.00	ND	0.10 ± 0.03	ND	ND
	11:00 am	12.00 ± 0.01	14.00 ± 0.11	0.38 ± 0.03	563.00 ± 0.50	ND	ND	ND	ND
	12:00 pm	10.00 ± 0.02	15.00 ± 0.05	0.47 ± 0.05	571.00 ± 0.04	ND	ND	ND	ND
	01:00 pm	6.00 ± 0.06	9.00 ± 0.03	0.35 ± 0.01	558.00 ± 0.10	ND	ND	ND	ND
	02:00 pm	4.00 ± 0.10	5.00 ± 0.01	0.32 ± 0.01	556.00 ± 0.02	ND	ND	ND	ND
	03:00 pm	9.00 ± 0.46	11.00 ± 0.01	0.33 ± 0.02	563.00 ± 0.15	ND	0.10 ± 0.00	ND	ND
	04:00 pm	14.00 ± 0.06	14.00 ± 0.06	0.37 ± 0.03	561.00 ± 0.04	ND	0.90 ± 0.01	0.10 ± 0.02	ND
Airport terminal	08:00 am	17.00 ± 0.11	21.00 ± 0.07	0.42 ± 0.04	631.00 ± 0.01	ND	2.90 ± 0.04	0.30 ± 0.01	ND
	09:00 am	12.00 ± 0.02	15.00 ± 0.05	0.38 ± 0.01	629.00 ± 0.05	ND	0.80 ± 0.02	ND	ND
	10:00 am	10.00 ± 0.04	11.00 ± 0.03	0.60 ± 0.00	606.00 ± 0.03	ND	ND	ND	ND
	11:00 am	11.00 ± 0.10	11.00 ± 0.10	0.44 ± 0.01	584.00 ± 0.01	ND	ND	ND	ND
	12:00 pm	4.00 ± 0.02	5.00 ± 0.02	0.49 ± 0.03	562.00 ± 0.02	ND	ND	0.10 ± 0.02	ND
	01:00 pm	8.00 ± 0.08	10.00 ± 0.20	0.37 ± 0.00	548.00 ± 0.01	ND	0.20 ± 0.01	ND	ND
	02:00 pm	12.00 ± 0.01	13.00 ± 0.04	0.43 ± 0.01	560.00 ± 0.04	ND	ND	ND	ND
	03:00 pm	14.00 ± 0.05	18.00 ± 0.06	0.39 ± 0.03	559.00 ± 0.25	ND	0.30 ± 0.05	0.10 ± 0.00	ND
	04:00 pm	10.00 ± 0.02	13.00 ± 0.01	0.41 ± 0.01	583.00 ± 0.42	ND	0.90 ± 0.00	ND	ND
CAA Headquarters	08:00 am	10.00 ± 0.08	11.00 ± 0.05	0.48 ± 0.04	586.00 ± 0.01	ND	1.60 ± 0.01	0.20 ± 0.03	ND
	09:00 am	11.00 ± 0.05	14.00 ± 0.01	0.40 ± 0.01	552.00 ± 0.80	ND	1.80 ± 0.00	ND	ND
	10:00 am	7.00 ± 0.10	8.00 ± 0.01	0.45 ± 0.03	567.00 ± 4.00	ND	ND	0.10 ± 0.01	ND
	11:00 am	8.00 ± 0.03	8.00 ± 0.01	0.39 ± 0.01	573.00 ± 2.00	ND	0.20 ± 0.01	ND	ND
	12:00 pm	6.00 ± 0.00	9.00 ± 0.03	0.41 ± 0.01	581.0 ± 0.04	ND	ND	ND	ND
	01:00 pm	9.00 ± 0.10	14.00 ± 0.04	0.40 ± 0.00	562.00 ± 0.05	ND	ND	ND	ND
	02:00 pm	12.00 ± 0.03	16.00 ± 0.10	0.36 ± 0.01	579.00 ± 0.01	ND	ND	ND	ND
	03:00 pm	11.00 ± 0.01	14.00 ± 0.01	0.47 ± 0.00	569.00 ± 0.14	ND	ND	ND	ND
	04:00 pm	17.00 ± 0.04	20.00 ± 0.05	0.41 ± 0.01	603.00 ± 0.20	ND	0.60 ± 0.01	ND	ND
Upper Hill of the Airport	08:00 am	6.00 ± 0.01	8.00 ± 0.02	0.48 ± 0.03	548.00 ± 0.24	0.009 ± 0.001	0.90 ± 0.02	ND	ND
	09:00 am	7.00 ± 0.03	8.00 ± 0.15	0.41 ± 0.00	550.00 ± 0.16	0.001 ± 0.000	0.70 ± 0.01	0.10 ± 0.04	ND
	10:00 am	5.00 ± 0.06	7.00 ± 0.01	0.35 ± 0.00	540.00 ± 0.01	0.003 ± 0.000	ND	ND	ND
	11:00 am	3.00 ± 0.06	3.00 ± 0.03	0.39 ± 0.02	554.00 ± 0.30	0.002 ± 0.001	ND	0.10 ± 0.01	ND
	12:00 pm	4.00 ± 0.02	5.00 ± 0.01	0.45 ± 0.10	562.00 ± 0.44	0.001 ± 0.000	ND	ND	ND
	01:00 pm	6.00 ± 0.11	6.00 ± 0.02	0.41 ± 0.01	548.00 ± 0.04	ND	ND	ND	ND
	02:00 pm	10.00 ± 0.04	11.00 ± 0.03	0.46 ± 0.03	542.00 ± 0.10	0.001 ± 0.000	ND	0.10 ± 0.00	ND
	03:00 pm	11.00 ± 0.01	11.00 ± 0.06	0.38 ± 0.01	538.00 ± 0.50	ND	ND	ND	ND
	04:00 pm	9.00 ± 0.03	10.00 ± 0.06	0.42 ± 0.00	550.00 ± 0.64	0.002 ± 0.001	0.20 ± 0.02	ND	ND

[a]ND: Not detected.

any other pollutant. Particulate matter is a complex mixture of solid and liquid particles of organic and inorganic substances (sulphates, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water) suspended in the air. PM_{10} have the potential to penetrate and lodge deep inside the lungs. Fine particulate matter ($PM_{2.5}$) is a concerning air pollutant, particularly if it exceeds the WHO limit of 25 μg/m^3 24-hour mean [40] because they can penetrate the lung barrier and enter the blood system. Chronic exposure to PM contributes to the risk of developing cardiovascular and respiratory diseases as well as of lung cancer [41].

Toxic volatile organic compounds (VOCs) like benzene, toluene, ethyl benzene and xylenes (BTEX) are atmospheric pollutants that present serious threats to human health [42] [43] [44]. Their emissions related to aircraft are not only during combustions but also result from resting losses from aircraft fuel tanks and during refuelling of the aircraft [45]. In this study, the concentration of VOCs was lower than the limit of 500 μg/m^3 [46]. VOCs such as 1,3-butadiene, benzene and vinyl chloride were classified by the International Agency for Research on Cancer in Group 1 as carcinogenic for humans [47]. They also cause eye and respiratory irritations, headache, dizziness, visual disorders as well as memory impairment [48]. At least 14 single or complex compounds are listed as hazardous by the Federal Aviation Administration, which in addition to polyaromatic hydrocarbons comprise acetaldehyde, 1,3-butadiene, n-hexane, acrolein, benzene, styrene, xylene, toluene, propionaldehyde, ethylbenzene, formaldehyde and lead compounds [49]. A recent study assessed 46 VOCs in the indoor air of the control tower maintenance room, potentially affecting employees, where a correlation was found between aircraft number and concentrations of light aldehydes/ketones [44].

Carbon monoxide and hydrogen sulphide concentrations were low (undetected in some cases) as compared to carbon dioxide concentrations. While the global trend is aiming at zero carbon dioxide emissions, the current study indicated that EBB produces substantial amounts of carbon dioxide which is a greenhouse gas. On the other hand, the current Occupational Safety and Health Administration permissible exposure limit for carbon monoxide is 50 ppm as an 8-hour time-weighted average concentration [50]. Carbon monoxide with its ability to combine with iron in haemoglobin may lead to carbon monoxide poisoning, a condition typified by headache, dizziness and drowsiness. Excessive exposure may cause loss of consciousness (coma) and ultimately death at high concentrations [51]. The 8-hour limit for hydrogen sulphide is 10 ppm and was not exceeded in this study. Exposure to this gas may cause eye, throat and nose irritations, bronchial constriction in asthmatic patients, spontaneous abortion, increased blood lactate concentration, decreased skeletal muscle citrate synthase activity, headache, dizziness, nausea, vomiting, coughing, difficulty in breathing, olfactory paralysis, convulsions and death in severe cases [52] [53].

Serious health risks also arise from exposure to ozone and sulphur dioxide. The WHO set 100 μg/m^3 8-hour mean as the guideline for ozone [41], which was not exceeded at EBB in this study (**Table 2**). Ground level ozone is one of the

Table 3. Average PM concentrations and AQI for the different locations studied at EEB.

Location	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	AQI ($PM_{2.5}$)	AQI (PM_{10})
Airstrip	8.1	9.88	0.810	0.494
Airport terminal	10.88	13.0	1.088	0.650
CAA headquarters	9.88	12.67	0.988	0.634
Upper hill of the airport	6.78	7.67	0.678	0.384

reactants in the formation of photochemical smog, along with nitrogen oxides (NOx) from vehicle and industry emissions and volatile organic compounds (VOCs) emitted by automobiles [54]. It is one of the six criteria air pollutants prescribed by the United States Environmental Protection Agency. At high concentrations in the air, ozone can trigger asthma, bronchitis and emphysema, cause breathing problems, reduce lung function or cause lung diseases [41] [55]. The WHO guideline for SO_2 is 200 μg/m^3 1-hour mean or 40 μg/m^3 (annual mean). This pollutant has effects on the respiratory system (the lungs) and causes eye irritation. Its ability to trigger inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis if inhaled at higher concentrations [41].

3.3. Health Risk Assessment Results

As indicated in **Table 3**, the results of risk assessment based on particulate matter indicated that the air quality indices were all less than 50, which corresponds to good air quality. A recent report indicated that the air quality index of EBB is 60, with the dominant air pollutant being $PM_{2.5}$ [56]. In the neighboring Kampala, monitored $PM_{2.5}$ data indicated that air quality of the city is typically at levels considered "unhealthy for sensitive groups" to "unhealthy" according to the United States Environment Protection Agencies Air Quality Index (AQI) [14].

4. Conclusion

Airports form part of an interconnected world but also have many accrued environmental footprints. This study established that Entebbe International Airport experiences irregular noise frequencies with the midday having the highest noise intensities. Though some of the air pollutants are below recommended threshold, carbon dioxide was recorded at higher concentrations. Therefore, the aviation authorities need to ensure that these air pollutants are monitored and controlled continuously. The expansion of EBB concurrent with the development of residential areas might increase the noise and air pollution if cleaner technologies are not embraced. Further studies should perform audiogram assessments (acoustic estimation of noise-induced hearing loss) at the airport.

Acknowledgements

The authors are grateful to the World Bank, the Inter-University Council of East

Africa (IUCEA) for the scholarship awarded to Waganesh Admase and Timothy Omara through the Africa Center of Excellence II in Phytochemicals, Textiles and Renewable Energy (ACE II PTRE) at Moi University (Kenya) which made this study possible. Elly Olomo and Jasper Okino are grateful to the Mobility for Innovative Renewable Energy Technologies (MIRET) scheme (under the Intra-Africa Academic Mobility Scheme of the European Union Funding) hosted at Moi University for the scholarships awarded to them that made this collaboration possible.

Conflicts of Interest

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

References

[1] Singh, A., Pope, F. and Avis, W.R. (2020) Visibility as a Proxy for Air Quality in East Africa. *Environmental Research Letters,* **15**, Article ID: 084002. https://doi.org/10.1088/1748-9326/ab8b12

[2] WHO (2018) Improving the Health Impacts of Airports. *Bulletin of the World Health Organization,* **96**, 518-519. https://doi.org/10.2471/BLT.18.020818

[3] International Civil Aviation Organization (ICAO) (2011) Doc 9889, Airport Air Quality Manual. ICAO, Montreal.

[4] Li, J., Yang, H., Liu, X., Yu, N., Tian, Y., Zhou, X., Zhang, P. and Wang, K. (2020) Aircraft Emission Inventory and Characteristics of the Airport Cluster in the Guangdong-Hong Kong-Macao Greater Bay Area, China. *Atmosphere,* **11**, 323. https://doi.org/10.3390/atmos11040323

[5] Boussauw, K. and Vanoutrive, T. (2019) Flying Green from a Carbon Neutral Airport: The Case of Brussels. *Sustainability,* **11**, 2102. https://doi.org/10.3390/su11072102

[6] Harrison, R.M., Masiol, M. and Vardoulakis, S. (2015) Civil Aviation, Air Pollution and Human Health. *Environment Research Letters,* **10**, Article ID: 041001. https://doi.org/10.1088/1748-9326/10/4/041001

[7] Woody, M., Baek, B.H., Adelman, Z., Omary, M., Lam, Y.F., West, J.J. and Arunachalam, S. (2011) An Assessment of Aviation's Contribution to Current and Future Fine Particulate Matter in the United States. *Atmospheric Environment,* **45**, 3424-3433. https://doi.org/10.1016/j.atmosenv.2011.03.041

[8] Mazaheri, M., Johnson, G.R. and Morawska, L. (2011) An Inventory of Particle and Gaseous Emissions from Large Aircraft Thrust Engine Operations at an Airport. *Atmospheric Environment,* **45**, 3500-3507. https://doi.org/10.1016/j.atmosenv.2010.12.012

[9] Turgut, E.T., Cavcar, M., Usanmaz, O., Yay, O.D., Dogeroglu, T. and Armutlu, K. (2017) Investigating Actual Landing and Take of Operations for Time-in-Mode, Fuel and Emissions Parameters on Domestic Routes in Turkey. *Transportation Research Part D: Transport and Environment,* **53**, 249-262. https://doi.org/10.1016/j.trd.2017.04.018

[10] Yang, X.W., Cheng, S.Y., Lang, J.L., Xu, R. and Lv, Z.J. (2018) Characterization of Aircraft Emissions and Air Quality Impacts of an International Airport. *Environment Science,* **72**, 198-207. https://doi.org/10.1016/j.jes.2018.01.007

[11] Bo, X., Xue, X., Xu, J., Du, X., Zhou, B. and Tang, L. (2019) Aviation's Emissions and Contribution to the Air Quality in China. *Atmospheric Environment*, **201**, 121-131. https://doi.org/10.1016/j.atmosenv.2019.01.005

[12] Zhou, Y., Jiao, Y.F., Lang, J.L., Chen, D.S., Huang, C., Wei, P., Li, S. and Cheng, S. (2019) Improved Estimation of Air Pollutant Emissions from Landing and Take of Cycles of Civil Aircraft in China. *Environmental Pollution*, **249**, 463-471. https://doi.org/10.1016/j.envpol.2019.03.088

[13] ASAP-East Africa Research Team (2020) A Systems Approach to Air Pollution—East Africa: Synthesis Report. https://assets.publishing.service.gov.uk/media/5eb16ef186650c4356562f91/ASAP_-_Air_Pollution_in_East_Africa_-_Synthesis_Report.pdf

[14] ASAP (2019) Air Quality Briefing Note: Kampala (Uganda), November 2019. https://assets.publishing.service.gov.uk/media/5eb16f3286650c4356562f92/ASAP_-_East_Africa_-_Air_Quality_Briefing_Note_-_Kampala.pdf

[15] Crilley, L.R., Shaw, M., Pound, R., Kramer, L.J., Price, R., Young, S., Lewis, A.C. and Pope, F. (2018) Evaluation of a Low-Cost Optical Particle Counter (Alphasense OPC-N2) for Ambient Air Monitoring. *Atmospheric Measurement Techniques*, **11**, 709-720. https://doi.org/10.5194/amt-11-709-2018

[16] Crilley, L.R., Shaw, M., Pound, R., Kramer, L.J., Price, R., Young, S., *et al.* (2020) Effect of Aerosol Composition on the Performance of Low-Cost Optical Particle Counter Correction Factors. *Atmospheric Measurement Techniques*, **13**, 1181-1193. https://doi.org/10.5194/amt-13-1181-2020

[17] Pope, F.D., Gatari, M., Ng'ang'a, D., Poynter, A. and Blake, R. (2018) Airborne Particulate Matter Monitoring in Kenya Using Calibrated Low-Cost Sensors. *Atmospheric Chemistry and Physics*, **18**, 15403-15418. https://doi.org/10.5194/acp-18-15403-2018

[18] European Union (2021) Impact of Aircraft Noise Pollution on Residents of Large Cities. https://www.europarl.europa.eu/RegData/etudes/STUD/2020/650787/IPOL_STU(2020)650787_EN.pdf

[19] Vidović, A., Štimac, I. and Zečević-Tadić, R. (2017) Aircraft Noise Monitoring in Function of Flight Safety and Aircraft Model Determination. *Journal of Advanced Transportation*, **2017**, Article ID: 2850860. https://doi.org/10.1155/2017/2850860

[20] Urassa, H.E., Mkoma, S.L. and Kihampa, C. (2014) Noise Pollution and Community Response to Aircraft Noise at the Kilimanjaro International Airport, Tanzania. *Tanzania Journal of Natural and Applied Sciences*, **5**, 752-756.

[21] Getzner, M. and Zak, D. (2012) Health Impacts of Noise Pollution around Airports: Economic Valuation and Transferability. In: Jacques, O., Ed., *Environmental Health—Emerging Issues and Practice*, IntechOpen, London, 247-272. https://doi.org/10.5772/29669

[22] Charlotte, C. (2015) Aircraft Noise Effects on Health. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/446311/noise-aircraft-noise-effects-on-health.pdf

[23] Basner, M., Clark, C., Hansell, A., Hileman, J.I., Janssen, S., Shepherd, K. and Sparrow, V. (2017) Aviation Noise Impacts: State of the Science. *Noise & Health*, **19**, 41-50.

[24] Mapper, G.C. (2004) EBB—Airport. Airport Information for HUEN. http://www.gcmap.com/airport/EBB.2004

[25] Google Maps, Road Distance between Entebbe Town and Entebbe International

Airport.
https://www.google.com/maps/dir/Entebbe/Entebbe+aircargo+transporter,+14+Kitaasa+Rd,+Entebbe/@0.0458161,32.43625,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x177d86b753c20ab3:0xa4a550c375cc2c14!2m2!1d32.463708!2d0.0511839!1m5!1m1!1s0x177d86cd37ba81af:0x9daba139d6433d1f!2m2!1d32.4417945!2d0.0435913!3e0

[26] Uganda Civil Aviation Authority, Entebbe International Airport. https://caa.go.ug/about-entebbe-international-airport/#:~:text=Entebbe%20International%20Airport%20lies%20astride,%2Dwater%2Dlake%2C%20Victoria

[27] Akan, Z., Körpinar, M.A. and Tulgar, M. (2011) Effects of Noise Pollution over the Blood Serum Immunoglobulins and Auditory System on the VFM Airport Workers, Van, Turkey. *Environmental Monitoring and Assessment*, **177**, 537-543. https://doi.org/10.1007/s10661-010-1654-6

[28] Kim, J., Kong, M., Hong, T., Jeong, K. and Lee, M. (2019) The Effects of Filters for an Intelligent Air Pollutant Control System Considering Natural Ventilation and the Occupants. *Science of the Total Environment,* **657**, 410-419. https://doi.org/10.1016/j.scitotenv.2018.12.054

[29] WHO (2018) Factsheet on Ambient Air Quality and Health. WHO, Geneva. http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[30] Wambebe, N.M. and Duan, X. (2020) Air Quality Levels and Health Risk Assessment of Particulate Matters in Abuja Municipal Area, Nigeria. *Atmosphere,* **11,** 817. https://doi.org/10.3390/atmos11080817

[31] US EPA (2014) Air Quality Index (AQI) A Guide to Air Quality and Your Health; EPA-456/F-14-002; U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Outreach and Information Division Research, Triangle Park, 1-12. https://www.airnow.gov/sites/default/files/2018-04/aqi_brochure_02_14_0.pdf

[32] US EPA (2014) Air Quality Index—A Guide to Air Quality and Your Health; Brochure; EPA-456/F-14-002. U.S. EPA, Washington DC. https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf

[33] Longinus, N.K., John, R.T., Olatunde, A.M., Alex, A.A. and Omosileola, J.A. (2016) Ambient Air Quality Monitoring in Metropolitan City of Lagos, Nigeria. *Journal of Applied Sciences and Environmental Management,* **20**, 178-185. https://doi.org/10.4314/jasem.v20i1.21

[34] AirNow, AirNow.gov—Home of the Air Quality Index: AQI Basics. https://airnow.gov/aqi/aqi-basics

[35] Suau-Sanchez, P., Pallares-Barbera, M. and Paül, V. (2011) Incorporating Annoyance in Airport Environmental Policy, Noise, Society Response and Community Participation. *Journal of Transport Geography,* **19**, 275-284. https://doi.org/10.1016/j.jtrangeo.2010.02.005

[36] Sadr, M.K., Nassiri, P., Hosseini, M., Monavari, M. and Gharagozlou, A. (2014) Assessment of Land Use Compatibility and Noise Pollution at Imam Khomeini International Airport. *Journal of Air Transport Management,* **34**, 49-56. https://doi.org/10.1016/j.jairtraman.2013.07.009

[37] Khaki, A.M. and Forouhid, A.E. (2014) Noise Pollution around the Airport with Noise Exposure Forecasting Modeling. *International Journal of Scientific and Research Publications,* **4**, 1-8. http://www.ijsrp.org/research-paper-0614.php?rp=P302837

[38] Cohen, B.S., Bronzaft, A.L., Heikkinen, M., Goodman, J. and Nádas, A. (2007) Air-

port-Related Air Pollution and Noise. *Journal of Occupational and Environmental Hygiene*, **5**, 119-129. https://doi.org/10.1080/15459620701815564

[39] ISO 1999:2013, Acoustics—Estimation of Noise-Induced Hearing Loss. 3rd Edition, 23 p. https://www.iso.org/standard/45103.html

[40] ASAP (2019) Air Quality Briefing Note: Nairobi (Kenya), November 2019.

[41] WHO (2018) Ambient (Outdoor) Air Pollution. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[42] Montero-Montoya, R., López-Vargas, R. and Arellano-Aguilar, O. (2018) Volatile Organic Compounds in Air: Sources, Distribution, Exposure and Associated Illnesses in Children. *Annals of Global Health*, **84**, 225-238. https://doi.org/10.29024/aogh.910

[43] Tsai, W.-T. (2019) An Overview of Health Hazards of Volatile Organic Compounds Regulated as Indoor Air Pollutants. *Reviews on Environmental Health*, **34**, 81-89. https://doi.org/10.1515/reveh-2018-0046

[44] Mokalled, T., Adjizian Gérard, J., Abboud, M., Liaud, C., Nasreddine, R. and Le Calvé, S. (2021) An Assessment of Indoor Air Quality in the Arrivals Hall of Beirut-Rafic Hariri International Airport: Monitoring of VOCs and NO_2. *Atmosphere*, **12**, 400. https://doi.org/10.3390/atmos12030400

[45] Schürmann, G., Schäfer, K., Jahn, C., Hoffmann, H., Bauerfeind, M., Fleuti, E. and Rappenglück, B. (2007) The Impact of NO_x, CO and VOC Emissions on the Air Quality of Zurich Airport. *Atmospheric Environment*, **41**, 103-118. https://doi.org/10.1016/j.atmosenv.2006.07.030

[46] TECAM (2021). https://www.tecamgroup.com/acceptable-voc-levels/#:~:text=Acceptable%20VOC%20levels%20in%20the%20air%20for%20human%20health,to%20be%20considerable%20or%20high

[47] International Agency for Research on Cancer. List of Agents Classified by the IARC Monographs. International Agency for Research on Cancer, IARC, Lyon, 1-105.

[48] ICAO. Contaminants from Aircraft Engine Emissions. https://www.icao.int/environmental-protection/pages/contaminants.aspx

[49] Federal Aviation Administration (2003) Select Resource Materials and Annotated Bibliography on the Topic of Hazardous Air Pollutants (HAPs) Associated with Aircraft, Airports and Aviation. Federal Aviation Administration Office of Environment and Energy.

[50] EPA. Carbon Monoxide's Impact on Indoor Air Quality. https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality#:~:text=Exposure%20Limits,-Occupational%20Safety%20and&text=%5BOSHA%20PEL%5D%20The%20current%20Occupational,CFR%20Table%20Z%2D1%5D

[51] Hall, R.M., Earnest, G.S., Hammond, D.R., Dunn, K.H. and Garcia, A. (2014) A Summary of Research and Progress on Carbon Monoxide Exposure Control Solutions on Houseboats. *Journal of Occupational and Environmental Hygiene*, **11**, D92-D103. https://doi.org/10.1080/15459624.2014.895374

[52] Simonton, S. and Morgan Spears, P. (2007) Human Health Effects from Exposure to Low-Level Concentrations of Hydrogen Sulfide. Occupational Health & Safety. https://ohsonline.com/Articles/2007/10/Human-Health-Effects-from-Exposure-to-LowLevel-Concentrations-of-Hydrogen-Sulfide.aspx

[53] Salas, V.B., Wiener, M.S., Badilla, G.L., Beltran, M.C., Zlatev, R., Stoycheva, M., Gaynor, J.T., *et al.* (2012) H2S Pollution and Its Effect on Corrosion of Electronic Components. In: *Air Quality—New Perspective*, IntechOpen, London, 263-285.

[54] Zhang, J., Wei, Y. and Fang, Z. (2019) Ozone Pollution: A Major Health Hazard Worldwide. *Frontiers in Immunology*, **10**, 2518. https://doi.org/10.3389/fimmu.2019.02518

[55] Liu, H., Liu, S., Xue, B., Lv, Z., Meng, Z., Yang, X., He, K., *et al.* (2018) Ground-Level Ozone Pollution and Its Health Impacts in China. *Atmospheric Environment*, **173**, 223-230. https://doi.org/10.1016/j.atmosenv.2017.11.014

[56] Weather Underground. Entebbe, Wakiso, Uganda Air Quality & Pollen. https://www.wunderground.com/health/ug/entebbe