International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:13, No:2, 2019

Spatial Distribution of Ambient BTEX Concentrations at an International Airport in South Africa

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***Abstract*—**Air travel, and the use of airports, has experienced proliferative growth in the past few decades, resulting in the concomitant release of air pollutants. Air pollution needs to be monitored because of the known relationship between exposure to air pollutants and increased adverse effects on human health. This study monitored a group of volatile organic compounds (VOCs); specifically BTEX (viz. benzene, toluene, ethyl-benzene and xylenes), as many are detrimental to human health. Through the use of passive sampling methods, the spatial variability of BTEX within an international airport was investigated, in order to determine 'hotspots' where occupational exposure to BTEX may be intensified. The passive sampling campaign revealed $BTEX_{total}$ concentrations ranged between 12.95–124.04 µg m^{-3}. Furthermore, BTEX concentrations were dispersed heterogeneously within the airport. Due to the slow wind speeds recorded (1.13 $m.s^{-1}$); the hotspots were located close to their main BTEX sources. The main hotspot was located over the main apron of the airport. Employees working in this area may be chronically exposed to these emissions, which could be potentially detrimental to their health.

***Keywords*—**Air pollution, air quality, hotspot monitoring, volatile organic compounds.

I. Introduction

AIR travel has experienced proliferative growth in the past few decades. Overall, aviation operations in the commercial sector are increasing rapidly worldwide. The growth rates in small, medium and large airports have shown to rapidly increase globally by 22%, 40% and 61%, respectively. Additionally, it has been noted that on average 4.6% of development will occur annually from 2010 to 2030 [1].

The impact of air travel on the environment is heavily debated, specifically in terms of radiative and cloud forcing, attributed to the release of emissions. These emissions are associated with emissions released at cruising altitudes, as well as emissions from take-off, landing and ground level activities within the airport; all contributing to the deterioration of air quality. The main reason that deteriorating air quality and increasing pollutant release is of concern to both environmentalists and the public as a whole, is due to the fact that exposure to air pollution has been linked to a concomitant increase in adverse short- and long-term health effects for plants, animals and humans [1]. In addition, air pollution can seriously impair visibility, may damage materials in buildings and cultural heritage and has direct and indirect effects upon climate [2]. While air pollution remains a major concern for developing countries; as a result of the rapid growth of population, energy demand and growth; over the past decade these countries have experienced a significant decline in the concentrations of many air pollutants [2]–[7].

A wide array of hazardous air pollutants (HAPs) originates from airports, which include particulate matter (PM), ultra-fine particles (UFP) and VOCs [8]–[10]. These types of pollutants are dependent on the source of pollution. Studies have revealed that pollutants such as UFPs, particle-bound polycyclic aromatic hydrocarbons, black carbon and NOx are present in the vicinity of various airports [11]. Spikes of these particular pollutants occur at aircraft take-off and landing. These studies concluded that the leading source of air pollution at airports originates from aircraft activities on the runway namely the landing and take-off (LTO) cycles [11], [12]. The findings were based upon conclusions about pollution levels by measuring background levels of pollution and calculating the weight of aircraft before and after take-off to measure the true value of pollutants originating from aircraft activities. Additionally, research has recently revealed that aircraft emissions at cruising altitude may have a greater impact on the air quality in Europe compared to the LTO cycles of aircraft, however intensive research needs to be focused on this specific area in order to make sound conclusions [13]. As can be seen, the release of emissions from aircrafts have had abundant attention due to their effects on local and regional air quality, however it is also important to highlight emissions caused from airport-related activities, as these emissions contribute to the overall ambient air pollution [2], [5], [9].

Emissions from aircraft exhaust are only one of many emission sources at airports [7]. Despite aircraft exhaust contributing to deteriorating air quality and increase in pollution, many other emissions sources have been noted to contribute to this deterioration in modern airports. These include amongst others: tires; brakes; asphalt wear; as well as the re-suspension of PM through the movement of aircrafts in upper air [2]. However, these emissions sources specific chemical and physical characteristics have been investigated

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The National Research Foundation of South Africa (grant number 99303) funded this research.

in only a few studies [14]. Moreover, the emissions of the units providing power to the aircraft on the ground have received relatively little consideration despite their potentially high impact on the local air quality [5], [7], [15]. Little attention has been given to auxiliary power units (APUs); ground power units (GPUs) (these units are small gas powered engines on-board on the aircraft, or outside the aircraft respectively, retained at each airport); or ground service equipment (GSEs) which can negatively affect air quality. GSEs include the ground vehicles used for passenger and luggage transport (such as baggage and food haulers, buses, refueling trucks, cleaning services, and tugs). Only a few studies are available on the air traffic-related emissions produced by ground services such as GSEs, GPUs or APUs (e.g. [5]).

In addition to the ground services, additional emission sources may occur from maintenance work, painting fumes, and heating/cooling facilities present at airports, as well as from refueling operations, kitchens and restaurants for passengers and operators, etc. [15]. Furthermore, as many airports are situated on the periphery of cities, their emission inventories should also take into account those sources which are not directly present within the airport terminals and runways, but which may still influence the regional climate. These sources may include intermodal transportation systems or road traffic including personal cars and taxis, shuttle buses and trucks used to transport goods (both within the airport precinct as well as outside). Emitted pollutants resulting from aviation include nitrogen oxides (NOx), sulfur oxides (SOx), PM, and VOCs [1]. Of particular concern are the HAPS; and more specifically, benzene and toluene, ethyl benzene and the three xylene isomers.

The United States Department of Transportation, Federal Aviation Administration has recently revealed that airports are a “hotspot” for BTEX due to the variety of fuel-related activities which occur within airports [16]. Due to the upsurge in airport usage, the expected level of BTEX emissions at airports is set to escalate [3]. The fact that BTEX emissions harm the environment as well as human life justifies the need for intensive research into the subject of BTEX concentrations. However, studies in South Africa, and the African continent as a whole, which focus on BTEX emissions, is constrained to a select few (e.g. [17]–[20]).

In South Africa, the aviation sector – comprising the airlines together with the airports, air navigation and other essential grounds services that make up the air transport infrastructure – carries over 21 million passengers and over 240,000 tons of air freight to, from and within the country [21]. More than 52,500 scheduled international flights depart South Africa annually, destined for 77 airports in 51 countries [21]. Domestically, more than 156,000 flights make over 17 million seats available to passengers annually, destined to 17 airports. These quantitative projections and the South African specific aviation sector profile, clearly indicate substantial aviation growth in the future.

Studies on the toxicity of BTEX around the world are well documented, yet little to no data are available on BTEX emissions within South Africa [17]. On top of this lack of data, there is minimal legislation surrounding the acceptable levels of BTEX in the ambient air of South Africa compared to the rest of the world, where stringent BTEX standards and legislation are enforced [22]. South Africa does have ambient air quality standards, however these are only stipulated for the criteria air pollutants, namely: Sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM_{10}), ozone (O_3) and benzene (C_6H_6) (where only one constituent of BTEX i.e. benzene is included).

Thus, the aim of this research is to determine the main hotspot locations with an international airport, using a passive sampling strategy, in order to determine the BTEX concentrations and potential for health impacts.

II. Materials and Methods

A. Study Site

The study was conducted at the Lanseria International Airport (25° 56’ 22.9’’S, 27° 55’ 32.1’’E), located in the Gauteng Province of South Africa, north-west of the Johannesburg metropolis (Fig. 1). The airport is situated at an altitude of 1370 m above sea level, with a relatively flat topography (Fig. 2).

The region encounters hot summers and cool winters with the majority of the rainfall occurring in summer as convectional rainfall [17]. The winter months experience persistent high pressure systems, causing stable atmospheric conditions to prevail for most of winter and a majority of the spring period [18].

The Lanseria International Airport was founded in 1974 and has a 3-kilometre-long, 45-meter-wide runway with advanced radar systems. Due to the length and width of the runway, as well as the complex radar systems available, the airport can cater from small piston engine aircrafts to jet engine aircraft. The airport allows for visual flight- and instrument flight-rules to take place. The airport acts as a regional and international hub for air travel.

The airport is frequented throughout the week due to local operating scheduled flights from the airport. The busiest time with regards to LTOs is during the morning (i.e. from 06:30 till 09:30). The airport has numerous avionics and aircraft maintenance companies, which are mainly situated on the eastern wing of the airport (Fig. 1).

B. Passive Sampling

Radiello passive samplers were used in the sampling campaign, as a variety of studies have conducted successful research using this specific methodology [23], [24]. This sampler is made up of an absorbing cartridge, which is located within a diffusive body that is comprised of polycarbonate and microporous polyethylene (Fig. 4). The sampler is supported on a polycarbonate plate that can be fixed onto a variety of structures [23], [24].

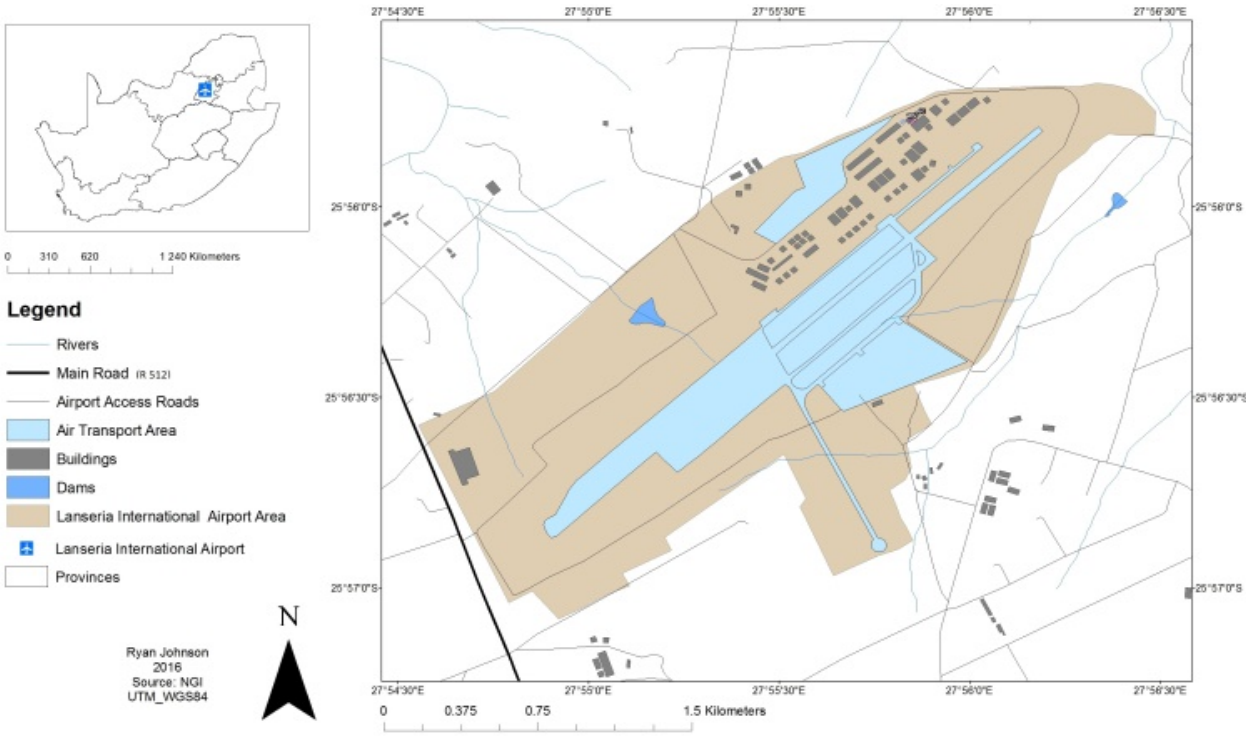

Fig. 1 Lanseria International Airport as the study site. (Map created on ArcMap 10.3 using NGI 2011 data)

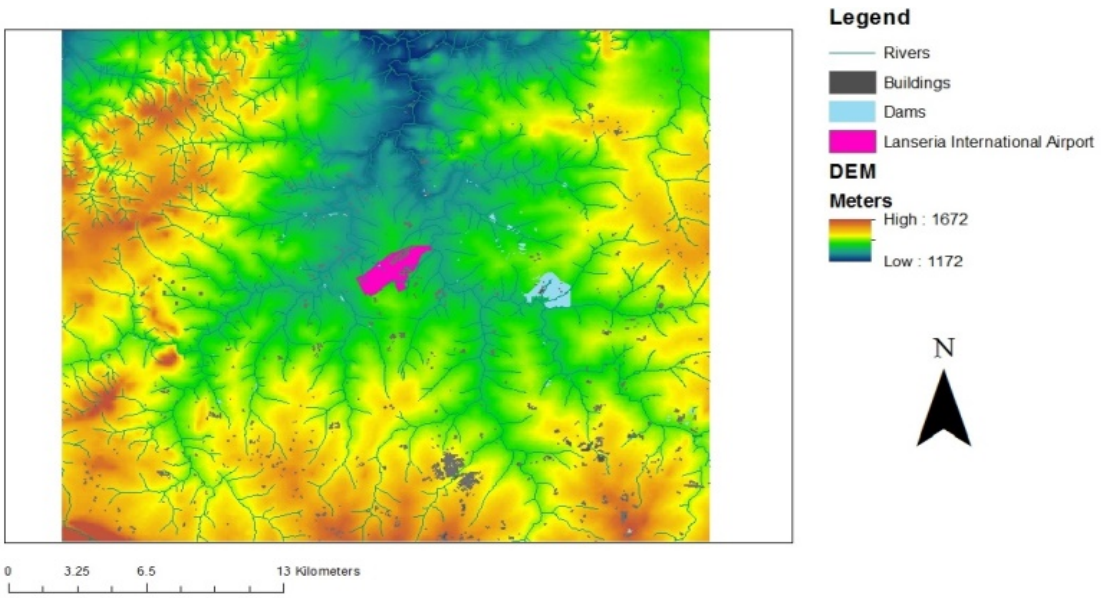

Fig. 2 Digital elevation model of the international airport used in the study. (Map created on Arc GIS 10.3 using NGI 2011 topographic data)

Passive samplers have been noted to have variety of benefits over active sampling methods. Some of these benefits include the fact that they are cost effective, easy to setup and require no external energy source. Due to these benefits, the passive sampling method has been utilized in a wide array of studies [3], [23], [24]. This diffusive sampler is an ideal instrument in which to analyze the spatial concentrations and distribution of BTEX with a degree of high precision. The downfall of passive samplers is that researchers cannot measure the temporal variation of BTEX with this sampling method due to the fact that the samplers work on a time averaged basis.

The Radiello Passive Samplers have a detection limit; this limit defines the lowest possible concentration that can be measured (Table I). An accredited laboratory (i.e. ChemTech Labs; complies by ISO guide 17025 requirements) analyzed

the passive samplers.

TABLE I
DETECTION LIMITS OF THE RADIELLO PASSIVE SAMPLER AS STATED BY CHEMTECH LABORATORY

VOC	Detection limit (µg.m^{-3})
Benzene	0.20
Toluene	0.23
Ethyl benzene	0.26
Xylene	0.24

As the detection rate of the sampler is affected by wind and temperature [23], a protective polycarbonate sheath was placed over the samplers protecting it. Seventeen passive samplers were mounted around the airport for a duration of 10 days. This allowed for the spatial variations of BTEX to be observed [19], [24]. Due to the varied spatial dispersion of the samplers around the airport (seen in Fig. 3), spatial isoconcentration maps were created through the Kriging interpolation technique. Isoconcentration maps are useful, as it allows to predict concentrations where sampling has not occurred [24]. This is possible through variogram modelling and statistical models which predict values between two or more points with known values [23].

TABLE II
BTEX CONCENTRATIONS (IN µG M-3) MEASURED USING RADIELLO SAMPLERS DURING THE SAMPLING CAMPAIGN AT THE VARIOUS PASSIVE SAMPLING POINTS, AS WELL AS THE TOLUENE/BENZENE (T/B) RATIOS

Passive sampler	Benzene	Toluene	Ethyl benzene	Xylene	BTEX total	T/B Ratio
1	5.78	11.08	2.01	9.24	28.11	1.92
2	4.86	10.72	2.06	10.27	27.91	2.21
3	5.09	13.38	2.21	10.66	31.34	2.63
4	4.87	8.8	1.68	7.7	23.05	1.81
5	4.77	8.4	1.63	7.36	22.16	1.76
6	4.72	27.44	16.87	75.01	124.04	5.81
7	4.19	12.52	2.12	9.91	28.74	2.99
8	4	7.46	1.43	6.56	19.45	1.87
9	3.83	6.46	1.29	5.63	17.21	1.69
10	3.07	4.89	0.92	4.07	12.95	1.59
11	3.34	5.03	1	4.31	13.68	1.51
12	3.25	4.94	0.93	4.22	13.34	1.52
13	3.56	5.8	1.08	4.85	15.29	1.63
14	5.19	19.81	2.31	10.93	38.24	3.82
15	4.7	10.43	1.87	8.93	25.93	2.22
16	4.77	8.4	1.61	7.36	22.14	1.76
17	17.91	54.27	7.06	36.11	115.35	3.03

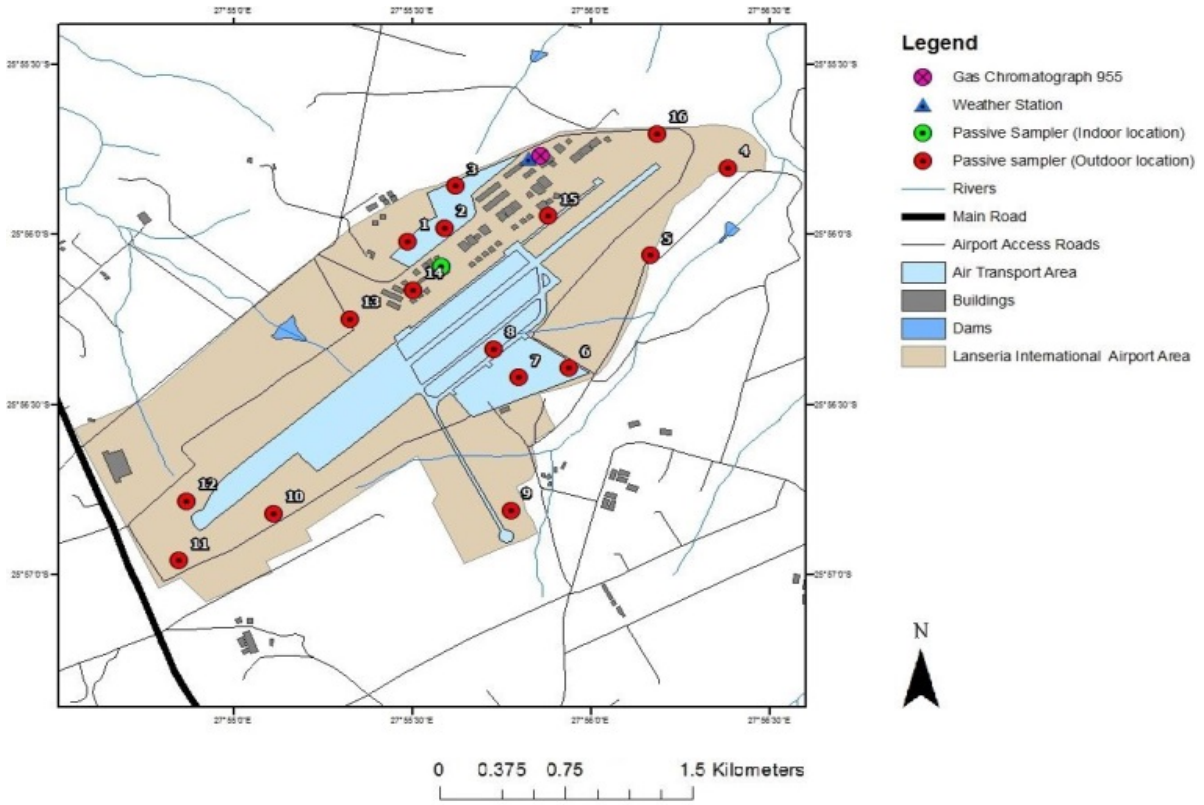

Fig. 3 The spatial distribution of the Radiello passive samplers located with the airport for the duration of the sampling campaign

III. RESULTS

The passive samplers were exposed to BTEX compounds for 10 days, allowing a time weighted average to be calculated for each sampler. The recorded concentrations are displayed in Table II along with the toluene/benzene (T/B) ratios.

The observed $BTEX_{total}$ concentrations ranged between 12.95 µg m^{-3} to 124.04 µg m^{-3}. Of particular interest is passive sampler 6, as values indicate that the concentrations measured

here relate to a point source of BTEX. It should also be noted that sampler 17 was an indoor sampler, and thus results may be slightly uncharacteristic as compared to others.

In order to investigate which regions of the airport were impacted by the different BTEX compounds, isoconcentration maps were created for each of the compounds (Figs. 4 and 5). Passive sampler concentrations that exhibited a ratio of T/B that was between 1-4 were utilized in the isoconcentration maps, as mobile sources have been flagged as the leading source of air pollutants at airports [5].

The one identified point source of pollution (passive sampler 6) was excluded, as this sampler had extremely high BTEX concentrations and would therefore skew the statistical variogram analysis. As previously mentioned, passive sampler 17 was located indoors, and thus was also excluded from the analysis.

The isoconcentration maps indicate that BTEX concentrations are heterogeneously dispersed over the airport according their main sources. Furthermore, they indicate specific hotpots over the main sources of BTEX at the airports. The main BTEX concentration hotspot was located over the main apron of the airport.

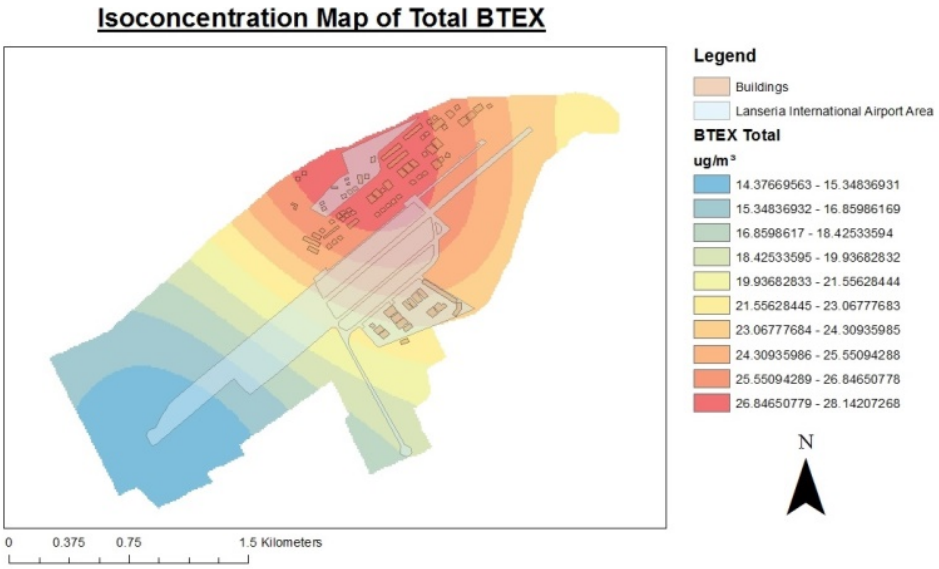

Fig. 4 Isoconcentration map indicating time weighted average of $BTEX_{total}$ concentrations

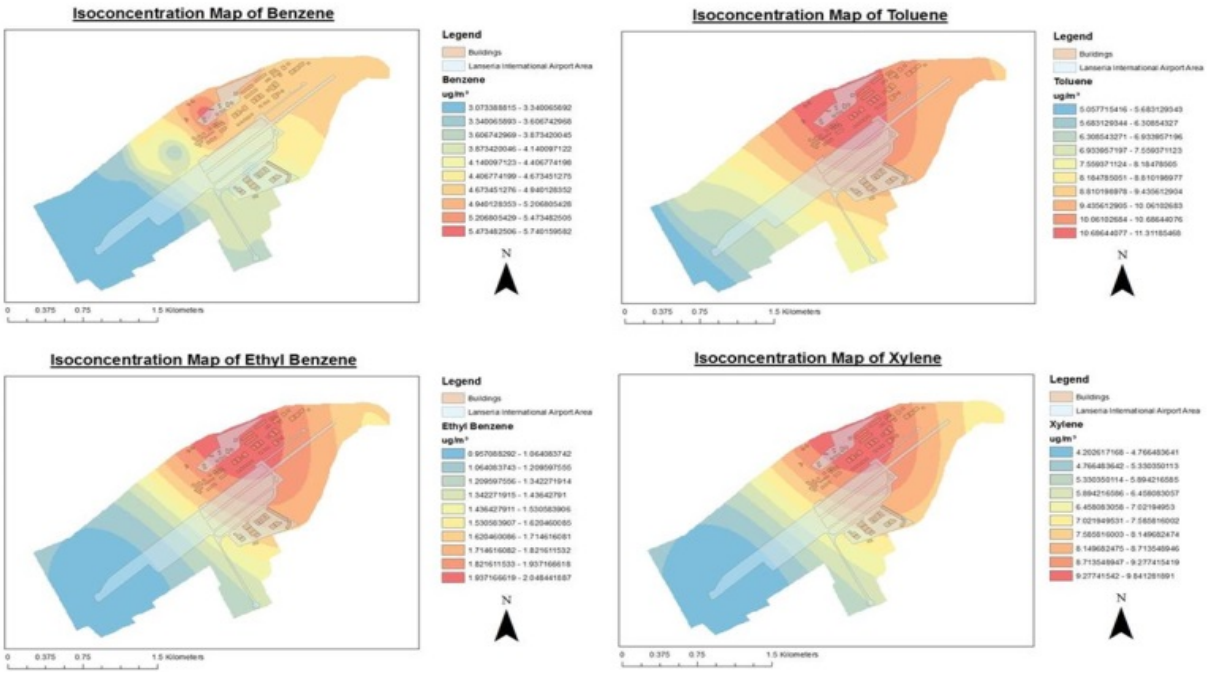

Fig. 5 Isoconcentration map indicating time weighted average of benzene (a), toluene (b), ethyl benzene (c), and xylene (d) concentrations

The measured wind speed over the sampling period was low, averaging 1.13 m/s. As noted by [25], air pollution dispersion is highly dependent on the velocity of the wind, thus low wind speeds will result in decreased rates of dispersion. The low wind speed, which occurred over the passive sampling campaign, meant that the BTEX were not dispersed far from their main sources. However, the effect of meteorology on reducing the concentrations of the outdoor passive air samples is evident when compared to the indoor passive sampler concentrations.

IV. Discussion

A study conducted by [3] which focused on BTEX emissions at Teterboro Airport in the USA, revealed a total averaged BTEX concentration of 5.68 μg m^{-3}. The fact that the measured concentrations at Lanseria International Airport are considerably higher (Table II), compared to the Teterboro Airport, warrants a need for concern. However, it should also be noted that differing results could be a consequence of the prevailing meteorological conditions; the season in which the samples were taken; the location of the samplers; as well as the amount of time the samplers were exposed to the ambient air. The observed concentrations in this study however, are similar to the observed results obtained by [9], in which, VOC concentrations at Zurich International Airport indicated significantly higher toluene concentrations as compared to the other BTEX compounds.

The first analytical process of the passive sampler concentrations was through the use of a toluene and benzene (T/B) ratio. The observed total T/B ratios were utilized in order to ascertain which samplers were under the influence of point source or mobile sources of BTEX [26], [27]. Research has revealed that varying T/B ratios indicate different sources of BTEX. T/B ratio values that are typically situated between 2 to 3 indicate mobile sources, while values between 3 and 4 indicate that the sampler may be under the influence of mobile and evaporative sources, and values above 4 indicate point sources of BTEX [26]–[28]. Toluene levels are abundant in the passive sampler concentrations indicating that the emissions were not a result of photochemical action [3].

As can be seen in Table II, passive sample 6 and sample 14 displayed the highest T/B ratios. It is noted that passive sampler 6 is most likely under the influence of a point source of BTEX while passive sampler 14 was under the influence of mobile and evaporative emissions [26]–[28]. These findings correspond to the respective locations of these samplers. Passive sampler 6 was located within 10 meters of the paint shop (paint is a known solvent that contain high levels of VOCs); thus confirming that this sampler was in fact under the influence of a point source of BTEX [15], [17], [29]–[31]. Passive sampler 14 was located at the main apron of the airport. The main apron of the airport is where the most fuel driven activities occur including the movement of aircraft and ground support vehicles [3], [9]. This is also the aircraft refueling area; thus indicating that the sampler was influenced by mobile and evaporative emissions. It is important to note the sources of BTEX concentrations at each sampling site in order to accurately interpret the spatial distribution of BTEX within the airport.

As can be seen in Fig. 4 the hotspot for $BTEX_{total}$ was situated over the main apron of the airport; which includes the main car park and the terminal of the airport. This is where the most amount of fuel driven activities take place including the movement of passenger vehicles, ground support vehicles, aircraft movement and the refueling of aircrafts [3], [9]. Due to these various fuel driven activities, $BTEX_{total}$ concentrations indicate a hotspot over this area. However, when the BTEX concentrations are analyzed as individual compounds, results differ. The isoconcentration map for benzene (Fig. 5 (a)) displays a specific hotspot located over the main car park. The emissions from motor vehicles have been noted to have particularly high concentrations of benzene due to the composition of petroleum and diesel [29]. The isoconcentration map for benzene also reveals that benzene concentrations stretch over the main buildings located in the north of the airport, as this area is characterized by a high volume of ground-support vehicle movement.

The isoconcentration maps for toluene, ethylbenzene and xylene (Figs. 5 (b)-(d), respectively) all revealed similar trends, with their main hotspots occurring over the main apron of the airport where airport activities are heightened. The isoconcentration map of toluene however revealed the greatest spread of increased concentrations (Fig. 5 (b)). This may be due to the fact [32] that jet fuel and avgas contains higher concentrations of toluene compared to benzene, ethylbenzene and xylene. Furthermore, the increased toluene concentrations are distributed out over the majority of the airport where aircraft movement is occurring. Previous studies (e.g. [3]) also revealed elevated levels of toluene concentrations where aircraft activities were highest.

Toluene concentrations at the airport follow a similar trend when compared to the other constituents of BTEX with decreased concentrations occurring at the threshold of runway 25. This may be due to the prevailing wind directions transporting BTEX away from this location in turn causing decreased concentrations. This area is free of buildings and obstructions allowing for greater dispersion and dilution of BTEX by the horizontal movement of air. Buildings are known to increase turbulence within the air thus affecting the way pollutants are dispersed [17]. The threshold of runway 25 is also located the furthest distance from the main apron of the airport, thus VOC emissions originating from the main apron of the aircraft are clearly having minimal impact on BTEX concentration levels at the threshold of runway 25.

An interesting observation with regards to the concentrations of BTEX at the airport was the concentrations observed at the indoor passive sampler location (Table II). This sampler was located at the apron office, which is situated directly adjacent to the main apron of the airport. This office has its doors regularly opened and closed, hence trapping BTEX within the office. This sampler reordered elevated concentrations across all BTEX compounds. These elevated levels may be due to the fact that indoor locations are hardly impacted by the effects of metrological conditions. This

highlights the role of atmospheric dispersion and dilution in decreasing BTEX concentrations within the ambient air. Similar results were revealed in the study of [3], where indoor samples were revealed to have higher concentrations than the outdoor samples.

V. Conclusions

The spatial investigation revealed that the BTEX hotspot was located in the vicinity of the main apron of the airport where fuel driven activities are heightened. However, when the individual BTEX compounds were analyzed, they displayed spatial variations that were dependent on their source areas such as motor vehicle and aircraft movement. It can therefore be concluded that their main source contributor predominantly influences the spatial variation of BTEX within the airport. The fact that the measured concentrations at Lanseria International Airport were considerably higher than other studies, warrants a need for concern, and further research. Through further intensive research into the matter of BTEX concentrations at the airport, mitigation measures can be successfully integrated in order to limit the detrimental effect of BTEX on human and environmental health within the airport.

Acknowledgment

The authors would like to thank Lanseria International Airport for allowing the research to be conducted on site.

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