International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-018-2116-x

ORIGINAL PAPER

Commuter exposure to particulate matters and total volatile organic compounds at roadsides in Addis Ababa, Ethiopia

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Received: 17 May 2018 / Revised: 28 September 2018 / Accepted: 12 November 2018

Abstract

People living in urban areas face different air-pollution-related health problems. Commuting is one of the high-exposure periods among various daily activities, especially in high-vehicle-congestion metropolitan areas. The aim of this work was to investigate the commuter exposure assessment to particulate matters with different aerodynamic diameter (< 1 µm to total suspended particles) and total volatile organic compounds using sensors called AROCET531S and AEROQUAL series 500, respectively. A total of 10 sub-cities at main roadsides of Addis Ababa, Ethiopia, were selected, and the sampling period was during commuting time. The geometric mean of particulate matters with different aerodynamic diameters and total volatile organic compounds regardless of sampling time were ranged 6.79–496 and 220–439 µg m^{-3}, respectively. The highest and the lowest concentrations for particulate matter with aerodynamic diameter 1, 2.5, and 4 µm pollutants were seen at Kolfe Keranio and Nefas Silk-Lafto sub-cities, respectively. And, highest and the lowest values for particulate matter with aerodynamic diameter 7 and 10 µm and total suspended particles were noticed at Addis Ketema and Gulelle sub-cities, respectively. Besides, the highest and the lowest values for total volatile organic compounds pollutants were noticed at Addis Ketema and Nefas Silk-Lafto sub-cities, respectively. The health risk assessment was conducted in accordance with the US Environmental Protection Agency standard which indicated that particulate matter with aerodynamic diameter 10 and 2.5 µm might induce the health problems, whereas the total suspended particles might not cause any health problems.

Keywords Health risk assessment · Outdoor air pollution · Total suspended particles · Vehicles sources

Introduction

Urbanization increases the health expectancy of the individual and decreases diseases caused by infection and malnutrition. However, expansion of industries, growing population, and vehicles number and continuing of use of biomass fuel are the major phenomenon seen during urbanization, where these phenomenon can cause for urban air pollution, and this can increase in chronic and non-communicable diseases such as cardiovascular disease, cancer, respiratory disease, and diabetes (Morakinyo et al. 2017; Petkova et al. 2013). The growing rate of urbanization in Africa is very fast that nearly 60% of the population of Africa is predicted to be living in cities in 2050, compared to < 40% in 2011. This is because rural populations continue to migrate to cities in search of employment and expectations of better living conditions in cities (Kinney et al. 2011). Moreover, the absence of good road network, increasing vehicle ownership, and prevalence of old, poorly maintained cars in urban cities aggravate the level of pollutants increase in most of the cities found in developing countries (Ekpenyong et al. 2012; Tefera et al. 2016). Thus, the problems related to air pollution will be increasing more in African population. Despite this, the researches related to urban air pollution in developing countries are very few.

Different substances such as particulate matters (PMs) (with different micro-diameter), carbon monoxide, nitrous oxides, sulfur oxides (principally from coal), total volatile organic compounds (TVOCs) (such as formaldehyde,

Editorial responsibility: U.W. Tang.

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Published online: 24 November 2018

benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene)) are the main harmful substances present in the outdoor air pollution (Fajola et al. 2014). Of the substances in polluted air, PMs and TVOCs are the major health concern in the world. This is because, once TVOCs and PMs pollutants enter into body, they can cause different health problems including conjunctive irritation, nose and throat discomfort, headache and sleeplessness, allergic skin reaction, nausea, fatigue and dizziness, leukemia, anemia, cancer, and damage to liver, kidney, and central nervous system (Chekwube et al. 2012; Ismail and Hameed 2013; Ojiodu 2013; Singh et al. 2012). For instance, $PM_{2.5}$ accounts for death of 800,000 people in cities around the world (Ekpenyong et al. 2012; Kinney et al. 2011). There is spatial and temporary variation in exposure to urban air pollutants within a given metropolitan city. Studies have shown that people commuting to work, walking, working at main roadsides, cycling, traveling by car, or public transport are exposed to high level of polluted air, which often does not meet air-quality standards (Cepeda et al. 2017; Ekpenyong et al. 2012).

United Nations Environment Programme (UNEP), 2011, has estimated that 90% the urban pollution in developing countries is attributed to motor vehicle emission (Kinney et al. 2011). Of the pollutants emitted to urban air by vehicles, particulate matter pollutants are the predominant (Cattaneo et al. 2010; Lee et al. 2012). WHO in 1996 has estimated that 60% urban air pollution caused by airborne particulate matters was due to diesel and gasoline engine by-products (Cattaneo et al. 2010). Similarly, one of the main problems faced by Addis Ababa nowadays is the availability of large number of old and poorly maintained vehicles which pollute the air highly. Studies showed that 53.5% of vehicles are more than 20 years old, while 29.3% are more than 30 years old (Alok 2011). The air pollution due to such vehicles might become worse unless the government or stakeholders formulate transport-regulating laws.

Furthermore, when dealing with the impacts of particulate matter on human and environment, the particle size is a very important factor. Visibility degradation also depends on the size of particulate matter. For example, particles smaller than 2.5 μm penetrate into the alveoli and terminal bronchioles; larger particles of up to 10 μm deposit primarily in the primary bronchi, and much larger particles (up to 100 μm) deposit in the nasopharynx which determine the their impact on health regardless of chemical composition (Araújo et al. 2014). However, the measurement of outdoor air particulate matter of different aerodynamic diameters is limited in Ethiopia (Etyemezian et al. 2005; Gebre et al. 2010). Moreover, there are no air-monitoring sites at roadside in Ethiopia.

Generally, the availability of data related to the level of air pollutants in Africa, particularly in Ethiopian cities, is less which hinders the health impact assessments, the development of cost-effective strategies to reduce the health burden due to outdoor air pollution, and the ability to influence urban transportation and planning policies in relation to air quality and health. As a result, this study was focused on short-term exposure assessment by measuring the concentration of outdoor PMs (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, and TSP) and TVOCs pollutants at roadside. Thus, the present study provides valuable knowledge for health risk assessments of pedestrians, street vendors, street sweepers, commuters, and traffic police officers who spend their time along and on the congested roadsides. PMs and TVOCs measurements were carried out between September 30, 2017, and November 15, 2017, for 8 h during congestion, and commuter queuing is expected to be high. Thus, the measurement was started exactly at 6:00 a.m. and continued for 4 h until 10:00 a.m. in the morning, and in the afternoon, the measurement was started exactly at 2:00 p.m. and continued for 4 h until 6:00 p.m. without any interruption. In general, in almost in all Ethiopian cities, the peoples and the students going to the workplace and the school were seen during morning time (6:00 a.m. to 10:00 a.m.) and afternoon (2:00 p.m. to 6:00 p.m.). Also, street vendors, street sweepers, and peoples who walk on the street for recreation purpose were observed during these time intervals. Hence, big congestion and queuing of peoples at the roadside and transport vehicles on the road has been observed.

Materials and methods

Description of study area

Ethiopia is the second most populous country in Africa continent (86.6 million, 2012, while the estimate for 2016 is 102.4 million), and metropolitan Addis Ababa has a population exceeding 3 million (ECSA 2012). The city has been growing at a rate of 2.1% from 1994 to 2010 (Do et al. 2013). Besides, Addis Ababa is situated at the center of the country at an altitude varying between 2200 and 2800 m above the sea level, between latitude 9.0300°N and longitude 38.7400°E. Average minimum and maximum annual temperatures range from 9.53 to 23.2 °C (Sanbata et al. 2014). A total of 10 sub-cities (three sampling points for each, all points served as a transportation corridor to downtown) at roadsides along the main road were selected for this study. The selection is based on the altitude difference, socioeconomic activities performed, and traffic activities. Accordingly, Arada, Gulelle, Kolfe Keranio, Lideta, Kerkos, Bole, Nefas Silk-Lafto, Yeka, and Akaki Kality sub-cities were selected for the study. The distance from the sampling points to the main road was in the range between 2.5 and 7.6 m. The altitude of sampling points varies between 2146 and 2657 m. The detailed characteristics of the sampling sites such as the position of the sampling points (including the distance from the road), major activities performed around sampling points, altitude and geographical locations are given in Table 1.

Sampling design and measurements methods

The exposure concentrations of PMs were measured by a portable sensor called AROCET531S (Met One Instrument., Inc. Grants Pass, OR 07526, USA). The limit of detection of the sensor was 0.1 μg m^{-3}. The instrument contains an ambient air-inlet nozzle, which is used for reducing the turbulence in air sample. It has also a temperature and humidity sensor, which is used for measuring the ambient temperature (AT) and relative humidity (RH). Thus, the zero-count filter was attached to the inlet nozzle until smallest particle size should have a count ≤ 1. The exposure measurement was carried out within 2-min interval until the measurement was ended, and it uses factory-calibrated flow rate, which is 2.83 L per min. The instrument was put on the kit 1.65 m above the ground which is built for this purpose (a position where it assumes most commuters breathe zone). The instrument uses a laser-diode-base optical sensor, which uses light scatter technology to distinguish, measure, and count particles. This detected information can be altered into particle mass using mass–density conversion factors or may be displayed as particles per size range, depending on how the AROCET531S is configured. Finally, the data are logged to the computer by using a cable provided by the company.

The exposure level of TVOCs was measured using an easy-to-use and portable sensor (AEROQUAL series 500; Aeroqual Limited, Auckland, New Zealand) with a 2-min interval. The sensor uses a factory-calibrated flow rate, which is 0.5 L per min while measuring. Besides, the instrument has photo iodide detector, and it was calibrated according to the manufacturer's protocol. Hence, the sensor was warmed up to burn off any contaminants, so the monitor is first switched on which will warm up for 3 min. Then, a zero calibration was done before each measurement using zero-grade air cylinder, and the reading is stabilized after 10 min. Finally, the instrument was ready for measurement, and it was kept side by side to the sampler of PMs at the same kit.

Generally, the whole kit was kept at distance 2.5–7.6 m far from main road depending on the peoples' locations in using it for waiting for taxi, commuter waking, and selling place by street vendors.

Statistical packages use in data analysis

A time series exposure concentration of PMs (μg m^{-3}) and TVOCs (μg m^{-3}) at 2 min interval was obtained from 30 sampling points. Then, the measured individual data of PMs were uploaded to the computer from sampling instruments using the cable connection and software provided by the company, whereas TVOCs data were recorded on notebook at a 2-min interval and fed to a computer manually. The data were further analyzed using different spreadsheet software after being entered into the computer. The statistical data analysis was carried out using IBM SPSS version 20.0, MicroCal™ Origin version 6.0 (MicroCal software, Inc. USA) and Microsoft Excel 2013. First Shapiro–Wilk test was used for the test of normality of the data. Then, Kruskal–Wallis sample test (which is used for a general comparison of all sub-cities at once) and Kruskal–Wallis K independent-sample test (which is used to compare just in pairs of sub-cities) were used to evaluate the significance of the differences in PMs and TVOCs concentrations across sub-cities. Finally, the Wilcoxon signed-rank test was applied to assess the significance difference in the concentration of PMs and TVOCs between morning and afternoon. The significant difference for all the tests was set to $p = 0.05$.

Results and discussion

Temporary variation in concentration of PMs and TVOCs at different sites

Shapiro–Wilks test was applied to the exposure concentration data of PMs and TVOCs across each sub-cities, and the result showed that the data were not normally distributed. Thus, the data were better described as log-normally distributed than normally distributed, that is, geometric mean (GOM) and geometric standard deviation (GSD) are better to report these data. The GOMs of PMs, TVOCs, AT, and RH measured at roadside in 10 sampling sites (three sampling points each) during morning and afternoon in this study are given in Table 2. The GOMs of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP, and TVOCs during the morning time were ranged 8.85–16.1, 20.9–50.3, 62.3–101, 129–216, 185–368, 269–613, and 232–508 μg m^{-3}, respectively. Hence, the highest and the lowest values for PM_1 and $PM_{2.5}$ were measured at Nefas Silk-Lafto and Kolfe Keranio, respectively. PM_4, PM_7, PM_{10}, TSP, and TVOCs highest value were seen at Addis Ketema sub-city, whereas their lowest values were seen at Nefas Silk-Lafto, Gulelle, Gulelle, Gulelle, and Akaki Kality sub-cities, respectively.

The GOMs of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs during afternoon time were ranged 4.96–13.2, 14.3–35.6, 36.7–75.3, 75.6–156, 116–288, 163–498, and 154–406 μg m^{-3}, respectively. Thus, the lowest and the highest values for PM_1, $PM_{2.5}$, and PM_4 were measured at Nefas Silk-Lafto and Kolfe Keranio sub-city, respectively. The highest and the lowest values for PM_7 and PM_{10} were measured at Akaki Kality and Arada sub-city, respectively. Similarly, the highest values for TSP and TVOCs were seen

Table 1 Location of PMs and TVOCs monitoring sites at Addis Ababa

Sampling sites	Sampling points	Geographical location of sampling sites	Altitude (m)	Distance from road (m)	Description of sampling sites
Gulelle sub-city	Addisu Gebiya	9°03′34.884″N; 38°44′14.610E	2606	3	Retail shops, street food sellers, and various other businesses, relatively low vehicle and pedestrian traffic, bus stop and near a roadside, pickup point for passengers, serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of northern parts
	Shiromeda	9°03′40.380″N; 38°45′42.982″E	2581	3.5	Retail shops, street food sellers, and various other businesses, relatively low vehicle and pedestrian traffic, minibuses stop and near a roadside, pickup point for passengers
	Arband Iyesus	9°03′20.862″N; 38°46′26.274″E	2524	4	Retail shops, shoeshine boys, and some restaurants, and relatively low vehicle and pedestrian traffic, minibuses stop and near a roadside, pickup point for passengers
Kolfe Keranio sub-city	Ayertena	8°58′59.172″N; 38°41′49.001″E	2528	4	Street fast food, tea and coffee sellers, and minibuses stop near a roadside and pickup point for passengers, and has high vehicle and pedestrian traffic at hours
	Asiko Bus Station	9°03′55.916″N; 38°41′37.272″E	2657	3.5	Retail shops, street vendors and various other businesses, and has high vehicle, pedestrian traffic major, minibus stop and near a congested, pickup point for passengers and rural bus station and one soap factory, it is also serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of western parts
	Lukanda 18	9°02′00.000″N; 38°42′53.544″E	2400	3.5	Commercial cooking smoke exhaust from roadside buildings, Café and restaurants, street vendors and various other businesses, heavy pedestrian and vehicle traffic at the commuting times, major minibus and bus stops and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of north western parts
Akaki Kality sub-city	Kality	8°53′43.458″N; 38°46′21.132″E	2146	6	Retail shops, street vendors and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus stop and near a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of southern parts, dust blowing from graveled road
	Kality Gebrieal	8°54′40.446″N; 38°45′49.674″E	2168	3	Few café and restaurants, many industries, some retail shops and various other businesses, and has high vehicle and pedestrian traffic at most of the days, the road at the sampling point is paved, and the road served for all types of vehicle (both heavy trucks and automobiles) serves as an important commuter route into and out of Addis Ababa and southern parts of Ethiopia, dust blowing from graveled road
	Maselitegna	8°55′56.724″N; 38°46′00.000″E	2259	3	Street vendors, very few cafes and various other businesses, and has high vehicle and pedestrian traffic at most of the days, most of the roads at the sampling point is paved, and the presence of highway approximately 200 m far from the sampling point which allows heavy trucks, dust blowing from graveled road
Lideta sub-city	Torayloch	9°00′39.318″N; 38°43′16.692″E	2407	5	Street vendors, supermarkets, and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus stop and pickup point for passengers, relatively low traffic congestions
	Mexico	9°00′40.002″N; 38°44′55.486″E	2373	3.7	Book shops, government institutions, café and restaurants, street vendors and various other businesses, and heavy pedestrian and vehicle traffic at commuting time
	Abenet	9°01′13.800″N; 38°44′02.124″E	2408	4	Retail shops, café and restaurants, street vendors and various other businesses, and has relatively low vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling

Table 1 (continued)

Sampling sites	Sampling points	Geographical location of sampling sites	Altitude (m)	Distance from road (m)	Description of sampling sites
Bole sub-city	Jakrose Square	9°00′12.198″N; 38°48′53.652″E	2344	3.3	Retail shops, café and restaurants, street vendors and various other businesses, and has high vehicle and pedestrian traffic, the availability of heavy truck is during sampling, congested pickup point for passengers
	Bole Bridge	8°59′18.402″N; 38°47′24.930″E	2357	4	Ethiopia international airport, hotels, supermarkets, street vendors and various other businesses, and has high vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling, compacted buildings building
	Saris Abo	8°56′38.610″N; 38°46′09.102″E	2252	4	Retail shops, café and restaurants, and various other businesses, and has highways which allows heavy truck and pedestrian traffic at commuters time, during sampling there was high wind
Nefas Silk-Lafto sub-city	Hana Mariam	8°56′07.350″N; 38°44′41.568″E	2365	2.5	Retail shops, café and restaurants, and various other businesses, and has high vehicle and pedestrian traffic at most of the days, road side is paved, and presence of highway which allows heavy trucks, dust blowing from graveled road
	Jemo	8°57′36.228″N; 38°42′44.454″E	2246	5	Street vendors, heavy pedestrian and vehicle traffic most of the day, major minibus and bus stop, nearly a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of south west parts
	Jermene Square	8°57′55.386″N; 38°44′01.806″E	2234	3.2	Retail shops, café and restaurant, and various other businesses, relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers, presence of highway approximately 250 m far from the sampling point which allows heavy trucks
Yeka sub-city	Megenagna	9°01′08.844″N; 38°48′03.126″E	2413	6	Near a major minibus stop, nearly a congested pickup point for passengers, many street vendors, street food sellers, many retail shops and other business centers availability of heavy tuck ways, has high vehicle and pedestrian traffic at most of the days
	Kara Kotebie	9°02′26.436″N; 38°51′50.940″E	2587	2.5	Retail shops, street vendors and various other businesses, low pedestrian and vehicle traffic most of the day, major minibus stop and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of northeast parts
	Lambert bus station	9°01′27.318″N; 38°49′10.434″E	2453	3.4	Retail shops, supermarkets, and various other businesses, and has high vehicle and pedestrian traffic
Addis Ketema sub-city	Medehani-yalem School around pastor	9°03′06.666″N; 38°43′18.120″E	2536	5	Retail shops, schools, hospitals, street vendors and various other businesses, and has relatively low vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling
	Merkato	9°01′46.212″N; 38°44′12.930″E	2445	4	In general, it the largest and compacted market center in the country where many peoples were available (general and retail shops, supermarkets, street venders and various other businesses), and has a very high vehicle and worker traffic at most of the days, many building under construction, some of road are paved
	Merkato Bus Station	9°02′01.458″N; 38°43′58.004″E	2506	5	Retail shops, street vendors and various other businesses, heavy pedestrian and vehicle traffic most of the day, major minibus and bus stops and near a congested and pickup point for passengers and serves as an important transfer point for minibuses and buses linking urban, peri-urban, and rural destinations of northern parts

Table 1 (continued)

Sampling sites	Sampling points	Geographical location of sampling sites	Altitude (m)	Distance from road (m)	Description of sampling sites
Kerkos Sub-city	Kera round	8°59′10.830″N; 38°44′53.830″E	2223	2.7	Many general and retail shops, café and restaurants, street vendors and various other businesses, and has high vehicle and pedestrian traffic, the some heavy truck has seen during sampling, street sweepers, slaughterhouse
	Agona	8°59′16.408″N; 38°45′34.680″E	2298	4.5	Retail shops, street food sellers, café and restaurant, and various other businesses, relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers
	Kasachis	9°01′00.000″N; 38°46′16.590″E	2363	3.2	Retail shops, hotels, street vendors and various other businesses, and has relatively low vehicle and pedestrian traffic, the availability of heavy truck is almost negligible during sampling
Arada sub-city	Black Lion	9°01′18.612″N; 38°45′ 09.150″E	2313	2.5	Retail shops, supermarkets, some governmental origination where many peoples are visit per day (Black Lion Hospital, immigration office and others) and various other businesses, and relatively medium vehicle and pedestrian traffic, bus and minibus stops near a roadside, pickup point for passengers,
	Arat Kilo	9°02′07.518″N; 38°45′ 46.549″E	2458	7.6	Café and restaurants, street vendors, supermarkets, both primary and secondary schools, Addis Ababa University, particularly Collage of Natural Sciences, and various other businesses, and has high vehicle and pedestrian traffic in most of the days (especially at commuter time)
	Piyassa (Minlk square)	9°01′59.382″N; 38°45′13.794″E	2464	4	General and retail shops, hotels, street vendors and various other businesses, and has relatively medium vehicle traffics, high pedestrian traffic, the availability of heavy truck is almost negligible during sampling (except public buses)

at Akaki Kality and Lideta sub-city, respectively, whereas their lowest values were noticed at Gulelle and Kolfe Keranio sub-city, respectively. This variation might be due to source route, patterns of traffic congestion, geographical and metrological factors (such as wind direction and wind speed) that need further study. Generally, the highest level of PMs in all sampling sites found in this study was seen during morning time, which showed a similar trend as in other studies (Aziz et al. 2015; Lee et al. 2012). The amount of AT and RH ranged between 15.6–25.4 °C and 27.8–55.2%, respectively, during the study period. The highest and the lowest value for RH was noticed at Gulelle M and Arada A, respectively, whereas highest and the lowest value for AT was noticed Arada M and Akaki Kality A, respectively.

Furthermore, the temporary variation in amount of PMs, TVOCs, AT, and RH within each sampling sites was calculated using Wilcoxon signed-rank test, and the results are given in Table 3. Wilcoxon signed-rank test showed a significant difference in concentration of PMs and TVOCs within the sampling sites between morning and afternoon at $p < 0.02$, except PM_{10} and TSP at Akaki Kality sub-city. Also, the relative humidity and temperature showed a significant difference between morning and afternoon measurements across the sampling sites which might affect resuspension, formation or growth of secondary particulate matter, and the dispersion rate of the pollutant. This variation might contribute to the change in concentration of PMs and TVOCs between morning and afternoon. In addition, besides temperature and humidity, other factors including background concentration, wind speed, wind direction, source routes, the pattern of traffic vehicles, and the proximity of other sources could have been the cause for the temporary variation (Zhao et al. 2013).

The overall geometric mean of PMs and TVOCs

Formulating of cost-effective strategies to reduce the health burden due to outdoor air pollution, the ability to influence urban transportation and planning policies in relation to air quality and health is vital for the metropolitan cities like Addis Ababa. Besides, ordering of sub-cities in accordance with their air pollution level is crucial to prioritize the action and to prevent further increase pollution. Hence, we have reported here the level of PMs and TVOCs pollutants in the 10 sub-cities regardless of their temporary variation, and the details of the results are depicted and described in Fig. 1 and Table 4, respectively.

The overall GOMs of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}, TSP and TVOCs were ranged between 6.79–14.4, 20.1–41.2, 48.9–84.6, 104–175, 148–300, 210–496 and 220–439 μg m^{-3}, respectively. The highest and the lowest values for PM_1, $PM_{2.5}$, and PM_4 pollutants were noticed at Kolfe Keranio and Nefas Silk-Lafto sub-cities, respectively, whereas highest and the lowest values for PM_7, PM_{10}, and TSP were noticed at Addis Ketema and Gulelle sub-cities, respectively. The highest and the lowest values for TVOCs pollutant were seen at Addis Ketema and Nefas Silk-Lafto sub-cities, respectively. The results of this study was compared with a pilot study conducted on measurement of PM_{10} and TVOCs in Addis Ababa, and the level of PM_{10} found in this study was higher than the previously reported value (35 and 97 μg m^{-3}), whereas the amount of TVOCs found in this study were comparable with the reported value studied at Addis Ababa which is in the range between 55 and 318 μg m^{-3} (Do et al. 2013). Also, the AT and RH were found in the range between 18.4–21.6 °C and 35.7–47.7%, respectively. The highest and the lowest values for AT were noticed at Kolfe Keranio and Arada, respectively, whereas the highest and the lowest values for RH were noticed at Gulelle and Arada sub-cities, respectively.

As shown in Fig. 1, the general trend for overall GOM of PMs level at roadside measurements was found to be in decreasing order of Addis Ketema > Kolfe Keranio ≈ Akaki Kality > Bole > Yeka ≈ Lideta ≈ Nefas Silk-Lafto > Kerkos > Arada ≈ Gulelle sub-cities, respectively. But, general trend for overall geometric mean of TVOCs level was found to be in decreasing order of Addis Ketema > Lideta ≈ Kerkos > Bole ≈ Arada ≈ Yeka > Gulelle > Kolfe Keranio ≈ Akaki Kality > Nefas Silk-Lafto cities, respectively.

Kruskal–Wallis sample test was applied to the data obtained from all the sub-cities, and the results showed significant differences in the concentration of PMs and TVOCs across all sub-cities ($p < 0.000$). However, one cannot recognize where this difference has occurred. Thus, the detailed pair comparison between sub-cities is necessary. Thus to do this, the data were normalized using the natural legalism, since the original data were not normally distributed. After this, the multivariate analysis test (post hoc test using Tukey's statistical test) was applied to the log-transformed data. Thus, PM_1 showed a significant difference across each site ($p < 0.003$), except during comparing of Gulelle versus Addis Ketema ($p = 1$); Arada versus Kerkos ($p = 0.67$); and Gulelle versus Lideta ($p = 0.14$); Arada versus Bole ($p = 0.08$); Addis Ketema versus Lideta ($p = 0.34$); and Akaki Kality versus Nefas Silk-Lafto ($p = 0.91$). Besides, $PM_{2.5}$ showed a highly significant difference across each site ($p < 0.04$), except during comparing of Gulelle versus Lideta ($p = 1$); Gulelle versus Addis Ketema ($p = 0.14$); Arada versus Bole ($p = 0.999$); Arada versus Kerkos ($p = 0.998$); Bole versus Kerkos ($p = 1$); and Yeka versus Akaki Kality ($p = 0.96$).

The concentration of PM_4 showed a significant difference across each site ($p < 0.03$), except during comparing of Kolfe Keranio versus Addis Ketema ($p = 0.55$); Gulelle versus Kerkos ($p = 0.64$); Gulelle versus Akaki Kality ($p = 1$); Gulelle versus Bole ($p = 0.56$); Gulelle versus Lideta ($p = 0.33$); Gulelle versus Arada ($p = 0.12$). Similarly, comparison of Arada versus Kerkos ($p = 0.99$); Arada versus Yeka ($p = 0.56$); Lideta versus Bole ($p = 1$); Akaki Kality versus Bole ($p = 0.72$); Yeka versus Kerkos ($p = 0.08$); Yeka versus Nefas Silk-Lafto ($p = 0.50$); Akaki Kality versus Lideta ($p = 48$); and Akaki Kality versus Kerkos ($p = 0.33$) did not show a significant difference in PM_4 concentration.

PM_7 showed a significant difference across each site ($p < 0.04$), except during comparing of Kolfe Keranio versus Addis Ketema ($p = 0.1$); Kolfe Keranio versus Akaki Kality ($p = 0.26$); Gulelle versus Kerkos ($p = 0.89$); Gulelle versus Arada ($p = 1$); Gulelle versus Nefas Silk-Lafto; Gulelle versus Nefas Silk-Lafto ($p = 0.63$); Arada versus Kerkos ($p = 0.86$). Similarly, comparison of Nefas Silk-Lafto versus Arada ($p = 0.56$); Bole versus Lideta ($p = 0.32$); Bole versus Akai Kality ($p = 0.36$); Yeka versus Lideta ($p = 0.34$); Yeka versus Kerkos ($p = 0.37$); Yeka versus Nefas Silk-Lafto ($p = 0.69$); and Kerkos versus Nefas Silk-Lafto ($p = 1$) did not show a significant difference in PM_7 concentration.

PM_{10} showed a significant difference across each site ($p < 0.04$), except comparing of Kolfe Keranio versus Akaki Kality ($p = 1$); Gulelle versus Arada ($p = 0.69$); Arada versus Kerkos ($p = 0.69$); Bole versus Yeka (0.22); Yeka versus Lideta ($p = 1$); Nefas Silk-Lafto versus Yeka ($p = 0.66$); and Lideta versus Nefas Silk-Lafto ($p = 0.93$).

TSP showed a significant difference across each site ($p < 0.03$), except during comparing of Kolfe Keranio versus Akai Kality ($p = 0.15$); Gulelle versus Arada ($p = 0.12$); Arada versus Kerkos ($p = 0.80$); Bole versus Yeka ($p = 1$); Bole versus Nefas Silk-Lafto ($p = 068$); Yeka versus Nefas Silk-Lafto ($p = 0.91$) and Lideta versus Nefas Silk-Lafto ($p = 0.55$).

TVOCs showed a significant difference across each site ($p < 0.03$), except during comparing of Kolfe Keranio versus Gulelle ($p = 0.07$); Kolfe Keranio versus Akaki Kality ($p = 0.08$); Arada versus Bole ($p = 0.98$); Bole versus Yeka ($p = 0.96$); Lideta versus Kerkos ($p = 1$); and Akaki Kality versus Nefas Silk-Lafto ($p = 0.98$).

Furthermore, although the concentration of pollutants in different sampling sites is expected to significantly differ, in some occasion, variations in pollutant levels in this study were not significant. This result might be due to the similarity in the main sources, for which transport vehicles and the sampler distance from the roadside might be the main reason. Thus, some of the sampling points were near to the roadside which collected emission close to the source

Table 2 Spatiotemporal level of PMs, TVOCs, AT and RH at different sampling sites

Sub-cities across sampling time	PM_1 ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	PM_4 ($\mu g\ m^{-3}$)	PM_7 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	TSP ($\mu g\ m^{-3}$)	TVOCs ($\mu g\ m^{-3}$)	AT (°C)	RH (%)
Addis Ketema A	8.95 ± 1.3	26.7 ± 1.5	63.0 ± 1.5	144 ± 1.5	246 ± 1.6	405 ± 1.7	382 ± 1.5	22.6 ± 1..3	35.4 ± 1.3
Addis Ketema M	14.7 ± 1.5	48.2 ± 1.5	101 ± 1.5	216 ± 1.6	368 ± 1.7	613 ± 1.8	508 ± 1.4	18.2 ± 1.4	42.4 ± 1.4
Akaki Kality A	5.31 ± 1.6	18.0 ± 1.7	56.5 ± 1.6	156 ± 1.7	288 ± 1.8	498 ± 2.0	221 ± 1.5	25.4 ± 1.2	31.3 ± 1.2
Akaki Kality M	9.05 ± 1.6	30.1 ± 1.7	66.5 ± 1.7	140 ± 1.6	229 ± 1.6	360 ± 1.6	232 ± 1.4	17.3 ± 1.2	51.8 ± 1.2
Arada A	7.19 ± 1.7	18.8 ± 1.9	39.4 ± 1.7	75.6 ± 1.9	116 ± 1.9	172 ± 2.0	271 ± 1.4	22.0 ± 1.3	27.8 ± 1.3
Arada M	13.1 ± 1.5	39.6 ± 1.7	77.5 ± 1.6	141 ± 1.6	213 ± 1.7	311 ± 1.8	393 ± 1.3	15.6 ± 1.2	45.4 ± 1.2
Bole A	6.77 ± 1.4	19.9 ± 1.6	48.5 ± 1.5	106 ± 1.5	170 ± 1.5	258 ± 1.5	268 ± 1.3	22.4 ± 1.3	34.0 ± 1.2
Bole M	12.0 ± 1.5	39.4 ± 1.9	86.5 ± 1.9	175 ± 1.9	278 ± 1.9	423 ± 1.8	373 ± 1.3	17.2 ± 1.3	45.5 ± 1.2
Gulelle A	9.05 ± 1.6	24.5 ± 1.8	47.8 ± 2.0	83.3 ± 2.2	118 ± 2.3	163 ± 2.5	238 ± 1.9	22.9 ± 1.3	41.2 ± 1.3
Gulelle M	14.0 ± 1.7	42.9 ± 2.0	77.6 ± 1.9	130 ± 1.8	185 ± 1.8	269 ± 1.8	307 ± 1.4	17.8 ± 1.4	55.2 ± 1.3
Kerkos A	7.99 ± 1.3	20.3 ± 1.5	41.9 ± 1.5	82.6 ± 1.5	130 ± 1.6	196 ± 1.7	378 ± 1.3	24.5 ± 1.2	35.5 ± 1.3
Kerkos M	13.1 ± 1.7	38.8 ± 1.6	77.4 ± 1.7	143 ± 2.0	214 ± 2.3	308 ± 2.6	399 ± 2.7	16.9 ± 1.2	52.0 ± 1.4
Kolfe Keranio A	13.2 ± 1.6	35.6 ± 1.5	75.3 ± 1.4	141 ± 1.4	224 ± 1.4	334 ± 1.5	154 ± 1.6	24.6 ± 1.1	31.0 ± 1.1
Kolfe Keranio M	16.1 ± 1.4	50.3 ± 1.5	98.1 ± 1.6	186 ± 1.7	292 ± 1.8	444 ± 1.8	450 ± 1.3	18.4 ± 1.1	45.4 ± 1.2
Lideta A	9.90 ± 1.8	24.5 ± 1.8	52.6 ± 1.9	107 ± 2.0	170 ± 2.1	256 ± 2.1	406 ± 1.5	23.8 ± 1.1	34.0 ± 1.2
Lideta M	15.2 ± 1.6	43.4 ± 1.7	84.0 ± 1.6	153 ± 1.6	230 ± 1.8	329 ± 1.9	379 ± 1.6	18.2 ± 1.2	47.3 ± 1.2
Nefas silk-Lafto A	4.96 ± 1.3	14.3 ± 1.4	36.7 ± 1.9	86.5 ± 1.5	149 ± 1.5	247 ± 1.6	195 ± 1.6	25.4 ± 1.1	29.1 ± 1.2
Nefas silk-Lafto M	8.85 ± 1.3	26.9 ± 1.4	62.3 ± 1.49	137 ± 1.6	229 ± 1.6	376 ± 1.7	244 ± 1.3	18.2 ± 1.1	48.9 ± 1.2
Yeka A	5.83 ± 1.5	17.0 ± 1.6	41.5 ± 1.59	98.6 ± 1.6	172 ± 1.7	289 ± 1.7	271 ± 1.8	23.0 ± 1.2	33.8 ± 1.1
Yeka M	9.75 ± 1.5	28.5 ± 1.6	62.4 ± 1.63	135 ± 1.8	225 ± 1.9	360 ± 2.1	356 ± 1.5	17.8 ± 1.2	49.9 ± 1.2

A afternoon, *M* morning, *AT* ambient temperature, *RH* relative humidity

with little dilution even if the number of emission sources was small. Whereas some of the measurements have done far from the roadside which is the dilution of pollutant that might be happening and the diluted level might rich to the sampler, although the large number of emission sources were available. Besides, the wind direction in reference to the emission sources and the sampler is also a primary factor.

In this study, the health risk assessment was carried out due to the exposure to $PM_{2.5}$, PM_{10}, and TSP. Human health risk assessment due to air contaminants depends on the type of pollutants and the extent of exposure. Hazard identification, dose–response assessment, exposure assessment, and risk characterization are the significant steps used in health risk assessment (Kushwaha et al. 2012; Matooane and Diab 2003; Morakinyo et al. 2017). We have gone through each of these steps to estimate the health risk due to PMs during the commuting time. In this study, although all PMs and TVOCs were identified as hazard contaminants in air, only $PM_{2.5}$, PM_{10} and TSP were considered due to unavailability of reference dose (RfD) values for other pollutants which are used in the calculation of hazard quotient (HQ). In the second step, ADD (average daily intake also called chronic daily intake) ($\mu g\ kg^{-1}\ day^{-1}$) was calculated using Eqs. (1) and (2). Annual threshold values for $PM_{2.5}$, PM_{10} and TSP set by WHO have been used as reference dose (RfD) while dealing with a dose–response step, and finally HQ was calculated in risk characterization step (Kushwaha et al. 2012; Matooane and Diab 2003; Morakinyo et al. 2017).

In this study the EF, ET, and ED for exposed person were determined based on different assumptions as shown in Table 5. The assumption considered includes the absence of exposed person in the study area, age, and inhalation rate. Adults (age above 19) were considered. The exposure frequency of 350 days/year assuming a person is not present in study area for 15 days in a year, and exposure duration of 46 years was taken by assuming the exposed person start his/her job at the age of 19 until she/he resigns his/her job at age

Table 3 Wilcoxon signed-rank test result for PMs, TVOCs, AT and RH at different sub-cities

	Nefas Silk-Lafto		Addis Ketema		Akaki Kality		Bole		Arada		Gulelle		Kolfe Keranio		Lideta		Kerkos		Yeka	
	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)
PM_1 at morning–PM_1 at afternoon	−10.9[a]	0.000	−12.9[a]	0.000	−14.2[a]	0.000	−12.9[a]	0.000	−13.1[a]	0.000	−12.7[a]	0.000	−4.70[a]	0.000	−13.6[a]	0.000	−11.8[a]	0.000	−13.3[a]	0.000
$PM_{2.5}$ at morning–$PM_{2.5}$ at afternoon	−10.8[a]	0.000	−13.0[a]	0.000	−13.2[a]	0.000	−12.5[a]	0.000	−13.0[a]	0.000	−12.2[a]	0.000	−6.57[a]	0.000	−14.5[a]	.000	−12.7[a]	0.000	−11.5[a]	0.000
PM_4 at morning–PM_4 at afternoon	−11.1[a]	0.000	−12.6a	0.000	−7.56[a]	0.000	−11.2[a]	0.000	−13.0[a]	0.000	−12.1[a]	0.000	−4.89[a]	0.000	−14.3[a]	0.000	−12.5[a]	0.000	−8.67[a]	0.000
PM_7M at morning–PM_7 at afternoon	−11.0[a]	0.000	−11.7[a]	0.000	−2.31[a]	0.021	−9.61[a]	0.000	−13.1[a]	0.000	−12.1[a]	0.000	−5.61[a]	0.000	−13.3[a]	0.000	−12.1[a]	0.000	−5.18[a]	0.000
PM_{10} at morning–PM_{10} at afternoon	−10.8[a]	0.000	−11.0[a]	0.000	−0.53[a]	0.596	−8.78[a]	0.000	−13.2[a]	0.000	−11.9[a]	0.000	−5.59[a]	0.000	−11.8[a]	0.000	−11.5[a]	0.000	−4.15[a]	0.000
TSPM–TSP	−10.4[a]	0.000	−10.4[a]	0.000	−.884[b]	0.377	−8.32[a]	0.000	−13.0[a]	0.000	−11.8[a]	0.000	−7.05[a]	0.000	−9.82[a]	0.000	−10.6[a]	0.000	−3.43[a]	0.001
TVOCs at morning–TVOCs at afternoon	−5.02[a]	0.000	−12.5[a]	0.000	−10.6[a]	0.000	−10.8[a]	0.000	−12.7[a]	0.000	−8.34[a]	0.000	−12.4[a]	0.000	−2.59[b]	0.010	−2.64[a]	0.008	−4.58[a]	0.000
AT at morning–AT at afternoon	−14.0[b]	0.000	−11.4[b]	0.000	−14.6[b]	0.000	−12.5[b]	0.000	−11.9[b]	0.000	−9.39[b]	0.000	−8.39[b]	0.000	−13.9[b]	0.000	−14.8[b]	0.000	−12.4[b]	0.000

Table 3 (continued)

	Nefas Silk-Lafto		Addis Ketema		Akaki Kality		Bole		Arada		Gulelle		Kolfe Keranio		Lideta		Kerkos		Yeka	
	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)	Z	Asymp. sig. (2-tailed)
RH at morning–RH at afternoon	−15.2[a]	0.000	−10.8[a]	0.000	−15.2[a]	0.000	−14.0[a]	0.000	−14.5[a]	0.000	−8.78[a]	0.000	−9.78[a]	0.000	−13.9[a]	0.000	−15.3[a]	0.000	−13.7[a]	0.000

[a]Based on negative ranks

[b]Based on positive ranks

of 65. Moreover, air intake rate for an adult is 20 m^3 per day, and for body weight, an adult Ethiopian is assumed to have African adult weight which is 60.7 kg (USEPA 1989; Walpole et al. 2012). The averaged time for concentration determination of PMs was 8 h, which is used as exposure time. Table 5 shows the details considered in HQ calculation.

Besides, US EPA classifies the exposure as acute (exposure duration is below 2 weeks), sub-chronic exposure duration (above 2 weeks and below 7 years), and chronic (exposure duration is above 7 years) types of exposure. The exposure duration of this study is above 7 years, and it is classified under chronic type of exposure. RfD for chronic type of exposure is used, and annual average of $PM_{2.5}$ (10 µg m^{-3}), PM_{10} (20 µg m^{-3}), and TSP (150 µg m^{-3}) values set by WHO and US EPA were used to calculate HQ (USEPA 2008; WHO 2010). The total overall geometric means of $PM_{2.5}$, PM_{10}, and TSP regardless of sampling sites have been used for health risk assessments.

For calculating of average daily intake (ADD) and HQ to characterize the health risk, Eqs. (1)–(3) are used (Matooane and Diab 2003; Morakinyo et al. 2017).

$$ADD = \frac{CA \times IR \times ED}{AT \times BW} \tag{1}$$

$$ED = EF \times ET \times DE \tag{2}$$

where ADD is the average daily intake (µg kg^{-1} day^{-1}); CA is the contaminants concentration in air (µg m^{-3}); ET is the exposure time spent (h day^{-1}); EF is the exposure frequency (days $year^{-1}$); IR is the intake rate (m^3 day^{-1}); ED is the exposure duration (days); DE is the duration of exposure (years); AT is the averaging time = DE × 365 days $year^{-1}$.

$$HQ = \frac{ADD}{RfD} \tag{3}$$

where HQ is the hazard quotient; EC is the exposure concentration obtained from Eq. (1); RfD reference dose (this will convert to the same unit as ADD (µg kg^{-1} day^{-1}), that RfD expressed in µg kg^{-1} day^{-1} would be equal to the RfD in µg m^{-3} multiplied by 20 m^3 air inhaled per person per day divided by 70 kg per person).

According to US EPA, if the HQ calculated is < 1, the contaminants could not induce any health impact on the exposed organism (human), whereas if its value is > 1, the contaminants induce/cause some health impacts on the exposed human (USEPA 1989). This study showed that no HQ value is greater than one for TSP, which confirmed TSP could not induce any health problems. However, the value of HQ for PM_{10} and $PM_{2.5}$ was greater than one, which indicates that both PM_{10} and $PM_{2.5}$ can introduce health problems due to their exposure. ADD for PMs and TVOCs and hazard quotients for $PM_{2.5}$, PM_{10}, and TSP are given in Table 6.

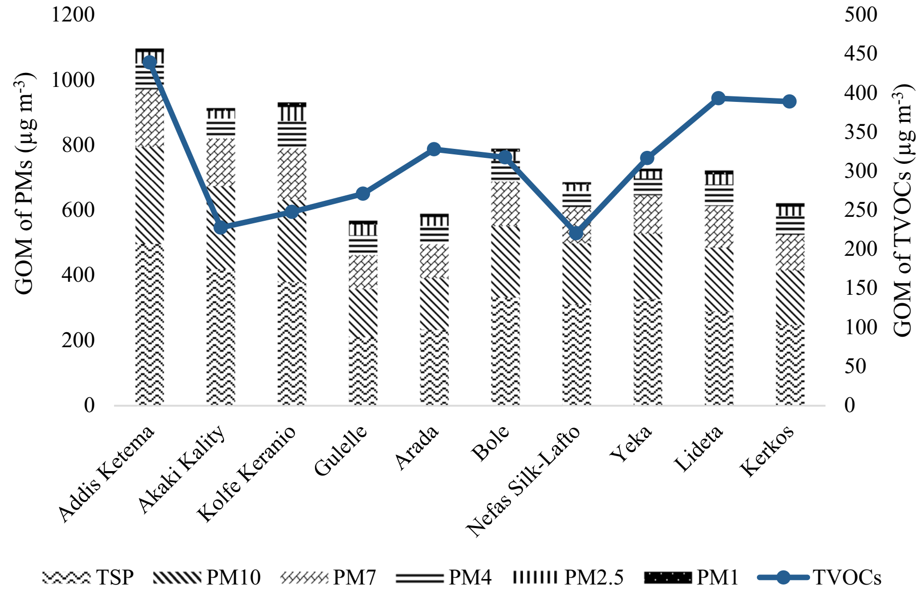

Fig. 1 Spatial variation of PMs and TVOCs at different sub-cities in Addis Ababa

Table 4 Overall geometric mean of PMs, TVOCs, AT and RH at different sub-cities

Sub-city	PM_1 (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_4 (µg m^{-3})	PM_7 (µg m^{-3})	PM_{10} (µg m^{-3})	TSP (µg m^{-3})	TVOCs (µg m^{-3})	AT (°C)	RH (%)
Addis Ketema	11.4 ± 1.7	35.6 ± 1.7	79.3 ± 1.5	175 ± 1.6	299 ± 1.6	496 ± 1.8	439 ± 1.3	20.4 ± 1.2	38.6 ± 1.3
Akaki Kality	7.05 ± 1.6	23.7 ± 1.8	61.6 ± 2.0	147 ± 2.3	254 ± 2.5	419 ± 2.7	227 ± 1.6	20.7 ± 1.3	41.0 ± 1.5
Arada	9.79 ± 1.7	27.5 ± 2.0	55.7 ± 1.9	104 ± 1.8	158 ± 1.8	233 ± 1.8	327 ± 1.5	18.4 ± 1.4	35.7 ± 1.5
Bole	9.05 ± 1.7	28.2 ± 2.0	65.1 ± 1.9	137 ± 1.9	219 ± 2.0	334 ± 2.1	317 ± 1.7	19.5 ± 1.3	39.4 ± 1.3
Gulelle	11.3 ± 1.4	32.5 ± 1.6	61.0 ± 1.6	104 ± 1.6	148 ± 1.6	210 ± 1.7	271 ± 1.5	20.2 ± 1.3	47.7 ± 1.4
Kerkos	10.3 ± 1.6	28.3 ± 1.6	57.3 ± 1.7	109 ± 1.7	168 ± 1.7	247 ± 1.6	389 ± 1.5	20.2 ± 1.3	43.2 ± 1.3
Kolfe Keranio	14.4 ± 1.5	41.4 ± 1.8	84.6 ± 1.6	159 ± 1.6	252 ± 1.6	379 ± 1.6	247 ± 2.9	21.6 ± 1.3	36.6 ± 1.5
Lideta	12.1 ± 1.5	32.2 ± 1.6	65.8 ± 1.5	127 ± 1.4	197 ± 1.4	289 ± 1.4	393 ± 1.3	20.9 ± 1.3	39.8 ± 1.3
Nefas Silk-Lafto	6.79 ± 1.8	20.1 ± 2.0	48.9 ± 1.9	111 ± 1.9	188 ± 2.0	310 ± 2.0	220 ± 1.4	21.2 ± 1.3	38.6 ± 1.4
Yeka	7.80 ± 1.6	22.8 ± 1.7	52.3 ± 1.7	118 ± 1.9	200 ± 1.9	327 ± 2.2	316 ± 1.6	19.9 ± 1.3	42.1 ± 1.3

Table 5 Exposure frequency, exposure time, intake rate, body weight, exposure duration, and averaging time (USEPA 1989; Walpole et al. 2012)

Exposure time (h day^{-1})	Exposure frequency (days $year^{-1}$)	Duration exposure (years)	Exposure Duration (days)	AT (days)	IR (m^{-3} day^{-1})	BW (kg)
8	350	46	5367	16,790	20	60.7

Table 6 ADD for PMs and TVOCs and hazard quotients for $PM_{2.5}$, PM_{10} and TSP

ADD	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADD for PMs and TVOCs (μg kg^{-1} day^{-1})							
ADD	1.02	2.99	6.54	13.4	21.5	33.1	32.4
RfD	–	3.24	–	–	6.56	49.4	–
HQ for $PM_{2.5}$ and PM_{10}							
HQ	–	1.05	–	–	3.78	0.77	–

Table 7 Comparison of levels of particulate matters at roadsides measured in different countries

City/country	Description of sampling sites and time	Particulate matter concentration (μg m^{-3})	References
Southern California, USA	Morning (7 a.m.–9 a.m.)	$PM_{2.5}$: 47.0–69.0	Boarnet et al. (2011)
	Midday (11 a.m.–1 p.m.)	$PM_{2.5}$: 38.6–70.7	
	Evening (4 p.m.–6 p.m.)	$PM_{2.5}$: 22.1–47.4	
Beijing, China	Close vicinity of the northeastern fourth-ring avenue (annual mean)	Overall mean PM_{10}: 175	Wang et al. (2014)
Nairobi, Kenya	Roadside (daily mean value)	PM_1: 23.9; $PM_{2.5}$: 36.6 and PM_{10}: 93.7	Pope et al. (2018)
Macao, Taipa	A background site on the roof and at roadside (hourly average)	$PM_{2.5}$: 1.1–53.3 for background and 6.4–68.7 for roadside	Song et al. (2014)
Nairobi, Kenya	Rush time during the morning and evening time at roadside	PM_{10}: 16.0–33.2 for morning and 20.3–32.3 for evening; PM2.5: 14.8–24.9 for morning and 11.5–23.0 for evening	Shilenje et al. (2016)
Cotonou, Benin and Abidjan, Côte d'Ivoire	Based on the weekly bases measurement at traffic sites	$PM_{2.5}$: 18.5–40.0 at Abidjan city; 14.0–57.0 at Cotonou city	Djossou et al. (2018)
Addis Ababa, Ethiopia	The sampler was put 2.5–7.6 m from main road side for 8 h [between 6:00 a.m. to 10:00 a.m. in the morning and 2:00 to 6:00 p.m. in the afternoon]	PM_1: (6.79–14.4); $PM_{2.5}$: (20.1–41.2); PM_4: (48.9–84.6); PM_7: (104–175); PM_{10}: (148–300) and TSP: (210–496)	This study

Discussion

Studies have shown that the concentration and the mixtures of traffic-related pollutants vary and decrease sharply within a distance moving from the traffic. Hence, peoples' such as pedestrians, street vendors, commuter to work, and street sweeper, who spend part of their significant daily time close to heavy traffic roads would generally be expected to show highest potential exposure to directly emitted pollutants from vehicle sources (de Nazelle et al. 2012). The overall GOM concentration of PM_{10} investigated in this study has been generally higher than the values reported in traffic police officer personal exposure assessment in Milan, Italy (Cattaneo et al. 2010). Previous studies showed the range of PM_{10} and the average of TSP pollutants measured for 24-h in Addis Ababa were found to be 17–285 and 195 μg m^{-3}, respectively (Tefera et al. 2016). However, the level of TSP found in this study is higher which was found in the range of 210–496 μg m^{-3}, whereas the concentrations of PM_{10} found were comparable with the maximum values. The variation might be due to the sampling time, the sampling points distance from expected sources, and other meteorological factors. Thus, the sampling for this study was carried out near the roadside, whereas the sampling in previous studies was far from the expected main sources (from road side where many vehicles are available) (Tefera et al. 2016). The result of this study also showed that $PM_{2.5}$ level is lower than the similar study conducted in Nigeria (Kinney et al. 2011). The variation might be due to the sampling point (such as the distance from roadway), the dispersion of pollutants factors (such as buildings, weather condition and pollution source), traffic volume, and composition of the fleet (gasoline, diesel) (Ragettli et al. 2013; Ramos et al. 2016).

Researchers from the different region of the world have reported the level of particulate matters measured at roadsides. The data of the present study have been compared with the data reported from different countries of the world. The comparative data are summarized in Table 7. As shown in Table 7, the level of particulate matters found in the present study is comparable with most of the studies conducted in other countries. However, there is some variation in their concentration among the studies. This variation might be due to the difference in metrological factors such as wind, atmospheric temperature, and humidity, the age of cars, other sources other than transport facilities and geographical location of the city.

Conclusion

Concentration of PMs and TVOCs has been investigated in 10 different sub-cities at the roadside of Addis Ababa. The pollution levels of PMs and TVOCs in Addis Ketema, Kolfe Keranio, and Akaki Kality sub-cites were relatively higher than from other sub-cities that might need intervention action to prevent further increments. Generally, the level of PMs and TVOCs emissions found in this study during afternoon was lower than the levels found in the morning. Thus, the commuter is subjected to lower degree of pollutants exposure during afternoon and hence less susceptible to the health risk. Furthermore, the health risk assessment has been evaluated using the overall GOM regardless of sampling sites. The hazard quotient value for TSP pollutant was not greater than one, which confirmed that only TSP exposure could not induce any health problems. However, the hazard quotients for PM_{10} and $PM_{2.5}$ were greater than

1, which revealed that PM_{10} and $PM_{2.5}$ will induce the health problems. Therefore, there is need to give awareness to the public and the stakeholders about the health impacts due to exposure to PM_{10} and $PM_{2.5}$ during commuting time so that they can look for the alternative solutions for the reduction of the roadside air pollution.

Acknowledgments The authors express their gratitude to the Department of Chemistry, Addis Ababa University for providing the laboratory facilities. Asamene Embiale is thankful to the Woldia University for sponsoring his PhD study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest in the publication of this article.

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