



# Air Quality at Public Transportation Stations/Stops: Contribution of Light Rail Transit to Reduce Air Pollution

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## Abstract

Air pollution from cars, vans and other different motor cars had observed in higher concentrations at public transportation stations. Now a day's air pollutants from public transportation, industry, cooking from firewood and dust production alongside main roads in Addis Ababa is increasing and affecting human health. Individuals who live and work close to streets seem to have an expanded occurrence and openness to medical issues related to transportation air contamination. Appropriately, the Addis Ababa Light Rail Transit was the main current mass transit framework in Ethiopia just as in Sub Saharan Africa launched in 2015. Thus, this study aimed to know the air quality at LRT, bus, taxi and mixed stations through an air tracking device, and health effect at sampled public transportation stations. Air quality data include particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>), air quality index (AQI), carbon dioxide (CO<sub>2</sub>), humidity and temperature with a half-hour observation through Air-Visual pro for every 24 purposively sampled stations from North to South LRT line. The average measured air quality indicated that higher than 35 µg/m<sup>3</sup> PM<sub>2.5</sub> and 100 AQI, which is unhealthy. Regards to this, 30 persons were questioned at all stations. Seven hundred twenty (720) persons in total to know the health effect of those living/working in and around the stations. The findings indicated that out of 720 respondents, 324 (45%) have experienced to air quality-related diseases residing and working proximity to the stations. These suggested that the aged vehicles, land-use, dust and design of bus-stop shelter for waiting passengers have increased exposure to vehicles air pollution. Consequently, peoples are exposing to air quality-related respiratory diseases particularly unhealthy for sensitive groups.

**Keywords** Air quality index · Public transportation · Station-design · CO<sub>2</sub> · Particulate matter · Health

## 1 Introduction

Addis Ababa, a capital city of Ethiopia, is experiencing rapid urbanization and population growth. The total population is expected more than 5.6 million inhabitants by 2021 and reach double figures within the next two decades (Voukas and Palmer 2012). In this regard, there is public transportations shortage, aged vehicles, traffic congestion and transport-related air pollution in the city. Air pollution generated

by road traffic in the city is a great concern in today's society. Since air quality has a significant impact on human health, even causing premature deaths (Diaz et al. 2017).

Ethiopia's Ministry of Health (MoH 2017) record showed that more than 800,000 individuals had been affected by breathing illness in Addis Ababa in 2018 because of air contamination. As per the air-quality investigation, it did in last year, the service of health affirmed that the air contamination level in Addis Ababa has passed the limit set by the World Health Organization (WHO 2005). Of the entire patients who visited for health treatment in health institutions, 819,900 or 27.2% of them were patients affected by a respiratory disease. A study result by Pongpiachan et al. (2017) on the risk of different magnitudes PM<sub>2.5</sub> bound metal concluded that ingestion of dust causes the more extensive risk to residents compared with inhalation and dermal contact. PM<sub>2.5</sub> a fine particle that travel long distance in the air and enter into human lung that causes for respiratory diseases (Orellano et al. 2020). PM<sub>2.5</sub> is the most

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dangerous pollutants  $PM_{2.5}$  as it can pass directly through human lungs and into the blood system. It is notorious for its role in increasing heart disease, emphysema, and lung cancer (Apte et al. 2015; Tong et al. 2015).

Public transportation can diminish the need for many separate trips by private vehicles in dense urban areas (Kasaw and Pandey 2021), replacing many separate emissions-producing vehicles with high capacity vehicles. Light rail transit and bus rapid transit that generally emit less or no pollution on a per person basis. Most rail transit vehicles emit few or no pollution, as they are powered by electricity.

Several occupants in Addis Ababa live in regions where urban pollution, particulate pollution, and  $CO_2$  from transport construction dust pose serious health concerns. The study by Koshy and Arasan (2005) portrayed that, current day trips and the design of transport stops could not take attention of air quality or exposure considerations for waiting passengers. The increasing population and the city extension requests have been spreading by construction all over Addis Ababa. Moreover, Vehicle conditions can play a major role in the emission source strength of carbonaceous aerosols (Pongpiachan et al. 2015). Understanding the temporal trends is of critical importance (Khongsai et al. 2021) to accurately forecast particulate matter concentrations and to mitigate human fine particles exposure (Zhao et al. 2018).

In general, public transportation users, bus-shelter design and location for waiting passengers, workers and residents proximity to major roads have been exposed to dangerous pollutants caused by personal vehicles and traffic congestion. These pollutants include carbon dioxide ( $CO_2$ ) and particulate matter ( $PM_{2.5}$  and  $PM_{10}$ ) was measured by Air visual pro. Nature, characteristic and design of the public transportation as well as land-use type at public transportation stations contributed to the quality of the air in and around the stations.

This study assessed air quality, station design, land-use type and health impact of vehicles air pollution at public transportation stations. LRT, bus and taxi stations surveyed using an air quality tracking device (Air-Visual pro). It also included air quality-related respiratory diseases health questionnaires surveyed within 500 m radius from the sampled stations.

## 2 Literature Review

### 2.1 Air Pollution in Urban Area and Its Source

One of the significant factors of poisons in the urban zone is public transportations (Khongsai et al. 2021). Old vehicles, motor sort and clogged street vehicles discharge more toxins (Gorham 2002). In such a manner, air contamination might be portrayed as the presence of toxic synthetics or mixes

(counting those of natural beginnings) noticeable all around, at levels that represent a wellbeing injury (Didier 2018). In a reasonable more extensive sense, air contamination implies the presence of synthetic substances or mixes with inside the air which are generally not existing and which bring down the nature of the air or cause a negative effect on the personal satisfaction (for example, the harming of the ozone layer or causing an unnatural weather change, health) (Chen et al. 2012). From regular poisons, carbon dioxide, an ozone-harming substance, is the principle toxin that is warming Earth. As Didier (2018) and Srivastava and Rao (2011) portrayed that human-being discharge carbon dioxide when they exhale, carbon dioxide is broadly considered as a poison when related to cars, planes, energy plants, and distinctive human exercises that include the copying of petroleum derivatives, for example, petroleum and flammable gas.

#### 2.1.1 Transport as a Source of Pollution

Transportation is the fundamental driver of air contamination from diesel outflows is turning into an expanded general concern, and, however, consideration had been principally centered on the car, business, concerns had likewise been raised about discharges from diesel rail vehicles (Hickman et al. 2018). Today, over 90% of vehicles on the street use gasoline and diesel engine (Lu 2011). Because of this, gasoline engine contaminations are carbon monoxide (CO), hydrocarbon (HC), carbon dioxide ( $CO_2$ ) and polycyclic fragrant hydrocarbons (PAHs); the fundamental worries of diesel fumes outflows poisons is particulate matter (PM). As indicated by Lu (2011) result confirmed that consuming gas fills radiate less PM and  $NO_x$  discharges than copying diesel powers, in any case, it creates roughly half more  $CO_2$  than diesel powers, and it also emanates around multiple times more CO and around multiple times more HC than diesel engine; copying diesel powers will deliver less  $CO_2$  outflows than gas powers, however, produce around multiple times more NOX and PM than gas powers. Subsequently utilizing fuel vehicles in urban regions may assist with lessening the human health impacts and death (Orellano et al. 2020); utilizing diesel vehicles on roads or in-country territories may assist with decreasing the ozone-depleting substance (GHG) depletions and reduce the worldwide temperature alteration impacts.

#### 2.1.2 Particulate Matter and Its Source

Suspended particulate issue (airborne soil) contains particles sufficiently little to stay suspended noticeable all around for significant stretches. Respirable particulate issue ( $PM_{10}$  and  $PM_{2.5}$ ) comprises of particulates of 10 microns or less in breadth for  $PM_{10}$  and 2.5 microns or less for  $PM_{2.5}$  those are sufficiently little to be breathed in, go through the respiratory

framework in the lungs with coming about health impacts (Vega et al. 2021). As a rule, Pisarski (2006) result portrayed that  $PM_{2.5}$  sources tend ignition sources such as vehicles, power age, mechanical cycles, and wood copying. Moreover, Choochuay et al. (2020) study showed that the main source of  $PM_{2.5}$  was a mixture of various combustion activities (e.g. biomass burning, vehicular exhaust, fossil fuel, coal, and industrial emissions). Five principal sources of  $PM_{2.5}$ , including vehicular exhaust, biomass burning, sea-salt aerosol, power plant, and industrial emissions. While  $PM_{10}$  sources incorporate these equivalent sources in addition to streets (28.8%) and cultivating exercises (23.5%). The source of  $PM_{10}$  is not only vehicles exhaust source from metals activity in urban area particularly manufacturing industry for instance iron (Fe), zinc (Zn), copper (Cu), lead (Pb), etc. release in urban air (Pongpiachan and Iijima 2016). In congested urban area, it increases the concentration of particulate matter in addition to transportation air pollution.

Most surveyed air quality investigation plans, especially travel arranged investigations, neglect to catch the openness for a travel benefactor holding up at a bus station. However, the bus station area is viewed (Moore et al. 2012) as perhaps the main parts of the travel course configuration, deciding travel framework execution, traffic stream, healthiness, and security (Moore 2012).

### 2.1.3 Age of Vehicles and Its Impact in Addis Ababa

Addis Ababa faces a quick boom in air pollutants in view of the expanding number of cars which do now presently do not notice air pollution regulation set through various concerned offices. Absence of retirement technique for old vehicles deteriorates the urban atmosphere. As per the investigation, Kante (2011) confirmed that the period of vehicles in Addis Ababa turned into that of 53.5% engine vehicles

have been extra than twenty years, simultaneously as 29.3% have been more noteworthy than 30 years collectible. Due to this contaminants produced by aged vehicles emit CO, CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, hydro carbon, volatile organic compound and particulate matter (Nasir et al. 2014). This proved that more prominent aged vehicles release further toxins into the weather. Accordingly, without carbon and elective transportations are significant to adapting to the creating requesting circumstances on quick urbanization including traffic crowdedness and moderate contaminations. In this respect, the authority of Ethiopia in the city of Addis Ababa is attempting to address the requesting transport problems and developing difficulties through presenting LRT along main route of the city.

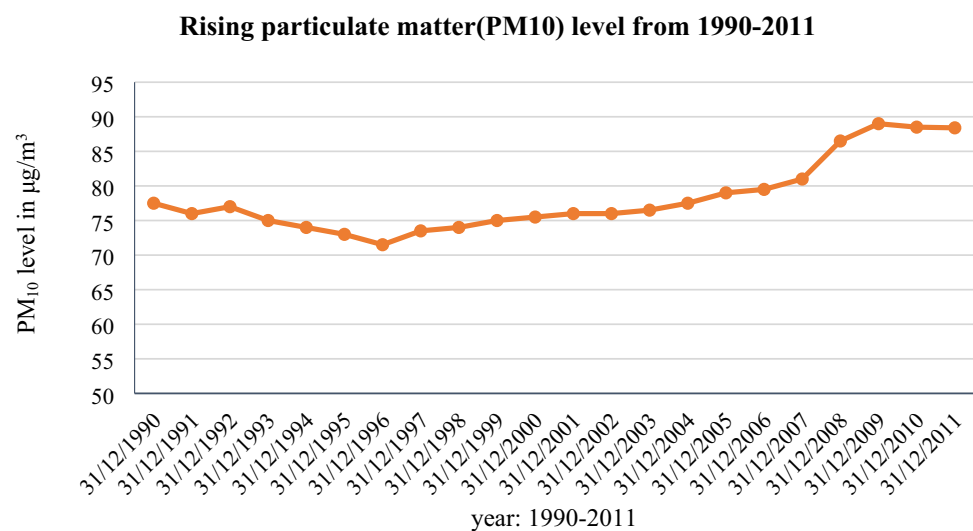
### 2.1.4 Increasing Particulate Pollution in Addis Ababa

The lonely accessible time-arrangement information on the particulate issue is from the World Bank (2015) record that has  $PM_{10}$  realities from 1991 to 2011. In pilot air toxins following glance at completed through the method of means, scientists from Desert Research Institute, Environmental Protection Authority of Ethiopia and Clark County Department of air quality administration in Addis Ababa eventually of 2004 dry season discovered 24 hourly  $PM_{10}$  focused between 35 and 97  $\mu\text{g}$  for each cubic meter all through 12 studying locales across the city (Figs. 1, 2).

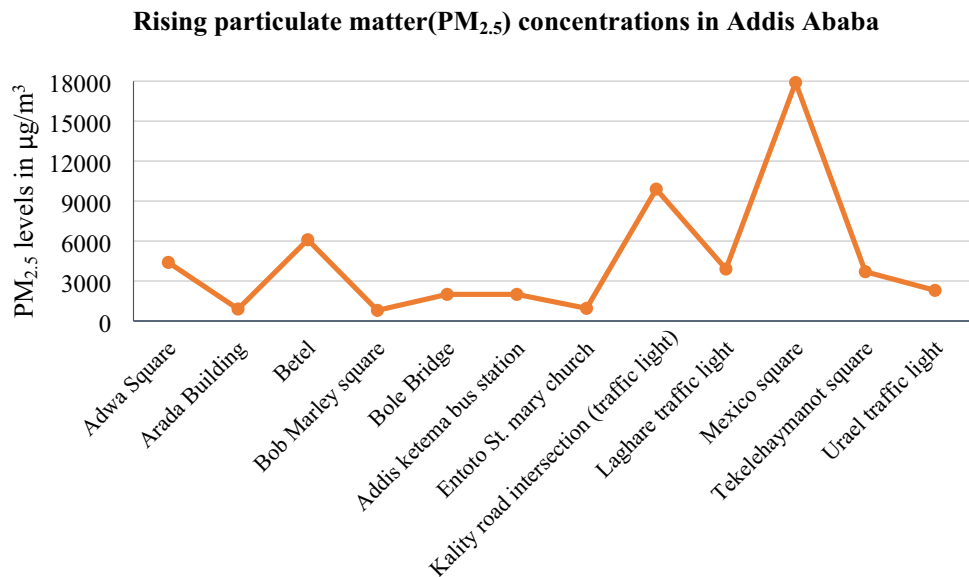
## 2.2 Health Effects of Particulate Matter and Carbon Dioxide

Both  $PM_{10}$  (huge) and  $PM_{2.5}$  (little) particles can cause respiratory diseases and health risks (Azhari et al. 2021; Tefera et al. 2020; Zhang et al. 2020). The  $PM_{2.5}$  risks further into the lungs due to its humbleness and poisonous. It

**Fig. 1** Rising particulate matter ( $PM_{10}$ ) levels. Source: (World Bank 2015). Ethiopia  $PM_{10}$  country level (micro-gram per cubic meter)



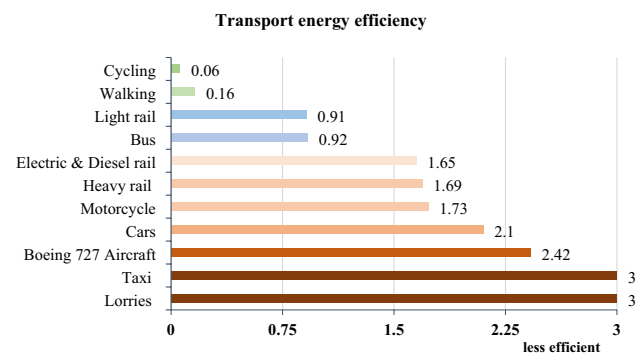
**Fig. 2** Rising particulate matter ( $PM_{2.5}$ ) concentration at public transportation stations. Source: (Zerihun 2015) impact of vehicle emission on air pollution in Addis Ababa



can directly pass through the human lungs and move into the blood system (Chen et al. 2016). Hitchins et al. (2000) result portrayed that  $PM_{2.5}$  can have more awful health effect than the larger  $PM_{10}$ . Thus, Exposure to particulate matter prompts increment operation of medicine and more visit to specialists because of respiratory illnesses. These illnesses incorporate emphysema, dry throat, fatigue, asthma, and related respiratory infections. A recent long travelling exposure of health impacts suggested that few epidemiologic studies of cancer have considered or accounted for work-related commuting (Dinu et al. 2019).

### 2.3 Transport Policy and Development

There are three general categories of transport strategies: infrastructure funds, value instruments, and guidelines. Funds involve assembling new transportation framework (for instance streets, railroads), repairing existing connections and innovation, or improving vehicle facility. As Berg et al. (2017) recommended that value motivators incorporate donations or charges to impact mode selection and transport conduct all the more by and large, for instance, understudy admission decreases, tolls, stopping routes, fuel duties, and clean transport sponsorships. Guidelines, rules to straightforwardly decrease air contamination (for example, fuel emanation norms, or driving limitations) or to arrange the vehicle area (for instance, cargo, taxis or transports). Because of this, some strategy involvement may influence supply, for example, infrastructure funds, though others target concern, as do transportation subsidizations (Fig. 3).



**Fig. 3** Mega joules per passenger's kilometer traveled, US energy-related  $CO_2$  emissions by sector and major fuel. Source: sustainable transport and public policy (Banister 2009)

#### 2.3.1 Transport Policy Implementation and Air Pollution Control

The electric railroad which was accomplished in mid-2015 would have liked to viably substitute half of the nation's requirement for fuel and the issues related to the air pollution. As per the information got from Addis Ababa City Administration, there are 600 city transports that are now being used in the city. These transports day by day devour 35 MT of diesel. The transports every day travel around 54,000 km in the city and are giving transportations to 1.5 million occupants. The late presented light rail travel in Addis Ababa has just gotten operational. There is additionally an arrangement to familiarize electric transports will be applied in any event in the city of Addis Ababa in the following not many years (AARTB 2018). All these can be

taken as articulations of activities intended to diminish air poisons from vehicles congestion in the city.

Moreover, a management system by limiting the access of traffic pollution sources (Manne and Kantheti 2020) and better managing public transport. Setting-up of a transport and environmental simplified model able to simulate in different scenarios the mobility and calculate the relevant vehicles emissions (Allegrini and Costabile 2004).

### 3 Research Method and Martials (Fig. 4)

#### 3.1 Research Approach

The researcher has been used both quantitative and qualitative method (mixed approach) to get data from 24 sampled stations/stops from Kality to Piassa LRT line.

In this regard, in quantitative aspect, air quality measurements by air tracking device (Air-Visual) and health questionnaires were prepared for residents, drivers, traffic police, shoeshines, street vendors, transport distribution controllers, street sweepers on and around sampled stations. In the qualitative aspect, unstructured interviews had been implemented to Addis Ababa City Road and Transport Bureau and Addis Ababa Environmental Protection Authority. Therefore, the techniques of data collection were an observation, interview, questionnaires, measurement of air quality by Air-Visual at 24 sampled (LRT, bus, taxi and both mixed) stations. Six stations were purposively selected for each of LRT, bus, taxi and bus/taxi. Having gathered the necessary data, data processing were performed with SPSS, Excel, and GIS software. The data were organized and analyzed using descriptive and inferential statistical methods i.e. (mean, count and simple linear regression analysis).

#### 3.2 Method of Data Collection and Source

Data sources were both primary and secondary types of data, accordingly four types of primary data collection were applied. The data source and methods have shown in Table 1.

#### 3.3 Sampling Frame and Size

There are 22 NS-LRT stations and 14 bus stops only, 21 taxi stations only and 14 are both bus and taxi stations along with the LRT corridor and surroundings (28 bus station and 35 taxi stations). Sample size selection was based on main nodal point that has 4, 5 and 6 intersection at North–South

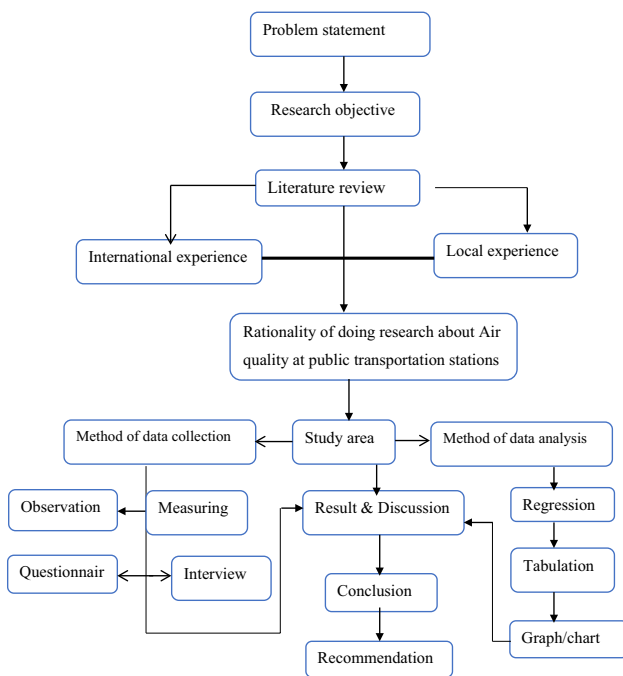


Fig. 4 Research design

Table 1 Method of data collection, type and sources

Data type	Method of data collection	Data source
Primary data	Measurement	Air-visual tracking device
	Personal observation	Visiting transportation stations, photo, counting
	Questionnaires	Street vendors, shoeshines, traffic police, transport coordinator, street sweepers, passengers, drivers, homeless
	Interview	AACTA, AAEP, AARTB, AALRTS,
Secondary data	Reading and reviewing different published and unpublished documents	Journal articles, books and government publications, CSA, internal records, websites

**Table 2** Sample size selection and distribution from the sampling frame

No.	Station	No. of stations	Sample size	Percent of sample stations (%)	Sample persons	Subtotals
1	LRT	22	6	27.27	30	180
2	Bus	14	6	42.85	30	180
3	Taxi	21	6	28.57	30	180
4	Both bus and Taxi	14	6	42.85	30	180
Total		71	24	33.80	30	720

LRT line of Addis Ababa. All the others non-sampled stations have a cumulative significant impact on air quality (Table 2).

At each six stations researcher purposively interviewed health questionnaires for 30 persons at every 24 stations. Train, Taxi, Bus, both Taxi and Bus. Hence,  $4 \times 180 = 720$  sample persons.

### 3.3.1 Studied Variables

The purpose of this study is to identify the relationship between health versus air quality and air quality versus station design at public transportation stations on NS-LRT line of Addis Ababa. First identify the cause and effect relationship between health, air quality and station design. Hence, the effect (dependent variable) and cause (independent variable) in the relationship between health, air quality and station design. The first relationship was health and air quality, health depends on air quality, in this case, the dependent variable is the health whereas, the independent variable is air quality (AQI, CO<sub>2</sub> and PM<sub>2.5</sub> value). In the other case, the relationship between air quality and station design, air quality depend on station design, in this case, the dependent variable is air quality and station design (at grade, shelter, land use, traffic volume) are the independent variables.

### 3.4 Method of Data Analysis and Presentation

Air quality data were collected two times for every 24 sam-

The analysis of the whole study was interpreted based on the nature of the data both qualitative and quantitative procedures had been employed. The health questionnaires were analyzed in quantitative method (graphs, tables, percentage, correlation and simple linear regression) and characteristic of the stations were analyzed in the qualitative method. Accordingly, those data the interviews and observations were described qualitatively whereas, the data obtained via questionnaires and air tracking device were analyzed and interpreted quantitatively. Air quality data interpreted based on US-EPA standards and health messages. As a result, the organized (analyzed) data were described in the form of tabulations, count, maps, text and graphs (descriptive statistics). In this case, tabulations, graphs and percentage were used to analyze the item of the health questionnaires (Table 3).

Current guideline of US-EPA for PM<sub>2.5</sub> standard is 35 µg/m<sup>3</sup>. Color is the key for correspondence goes from 0 to 500 (no units) gives a pointer of the nature of the air and its wellbeing impacts. Furthermore, simple regression analysis had used to quantify the relationship of air quality index and health impacts at public transportation (LRT, Bus, and Taxi) stations of North–South LRT corridor in Addis Ababa.

According to Anyadike, the simple regression equation used in the form:

$$Y = a + bX.$$

$Y$  is dependent variable (effect) represent the magnitude of the relationship between health and air quality (CO<sub>2</sub>, PM<sub>2.5</sub>, AQI)  $a$  is the constant (intercept) that scales the equation,

**Table 3** Air quality categories, standards and health messages

AQI value	AQI color	PM <sub>2.5</sub> (µg/m <sup>3</sup> )	PM <sub>10</sub> (µg/m <sup>3</sup> )	CO <sub>2</sub> (ppm)	AQI category and health messages
0–50	Green	0–12.4	0–54	< 700	Good
51–100	Yellow	12.5–35.4	55–154	701–1000	Moderate
101–150	Orange	35.5–65.4	155–254	1001–1500	Unhealthy for sensitive groups
151–200	Red	65.5–150.4	255–354	1501–2500	Unhealthy
201–300	Purple	150.5–250.4	355–424	2501–5000	Very unhealthy
301+	Maroon	250.5+	425+	5001+	Hazardous

Source: US-EPA (2006)

ple stations (for a half-hour during peak and off-peak hours).

$b$  represents regression coefficients of the independent

variables.  $X$  represents independent variables (cause) air quality ( $PM_{2.5}$ ,  $PM_{10}$ ,  $CO_2$ , and AQI).

## 4 Result

Transportation is necessary for economic and social development, yet it is associated with environmental problems, especially concerning air quality-related health impacts. Its emissions incorporate ozone-harming substances, most quite  $CO_2$ , just as particulate matter, sulfur oxides and unstable natural mixes. The most dangerous and studied pollutants were  $CO_2$  that is increasing global warming, health risks and  $PM_{2.5}$  is also the most dangerous particle affecting human health and travel long distance on air. In this regard, station design, bus shelter orientation, and street greenery, age of vehicles and traffic congestion in Addis Ababa are being increased the emission level at public transportation stations and long waiting passengers have been exposing to vehicles pollution. 720 persons were surveyed at sampled public transportation stations. These samples focused on especially peoples living/working in and around the stations. Forty-five (45%) of out of 720 respondents are exposed by transport-related air pollution diseases. This indicates that the main victims are street vendors, street sweepers, traffic police, transport coordinators and shoe shines.

### 4.1 Demographic Characteristics of Health Respondents

Out of total (720) respondents, 420 (58%) are males whereas, 300 (42%) are females. Age composition of respondents categorized into seven age categories. Below 15 years old, the five categories grouped by 10 years difference and the remaining category is above 65 years old. The higher proportion of respondents was age between 26 and 35 (39.0%), 15–25 (34.7%) and 36–45 (17.40%), respectively. Whereas, the least number of respondents were above 65 (1.00%), 56–65 (1.30%), 46–55 (3.20%) and under 15 years old (3.50%), respectively. Those health questionnaires took from six major stations in six sub-city of Addis Ababa (see Fig. 5) at each stations 4 sampling was taken for LRT, bus, taxi and mixed stations ( $4 \times 6 = 24$  sample stations).

Public transportation stations have bad air quality in Addis Ababa as a result, respiratory diseases are triggered or worsened by poor transport-related air pollution. Clogged traffic passageways in dense metropolitan zones are a key contributor of the degrading of metropolitan air quality. While holding up at transport stops, travel riders might be presented to more prominent measures of vehicle-based contamination  $CO_2$ , including particulate issue ( $PM_{2.5}$ ,  $PM_{10}$ ), on account of their nearness to the street. Most stations in the study are a suited close to street convergence where there

are high traffic movement and nodal point. As clarified in this study; bus shelter location and orientation was found to principally influence the grouping of sizes of particulate matter ( $PM_{2.5}$  and  $PM_{10}$ ) (Fig. 6).

At peak hours,  $PM_{2.5}$  was increasing to  $560 \mu\text{g}/\text{m}^3$  and changing the value continuously minimum concentration  $51 \mu\text{g}/\text{m}^3$  and also  $PM_{10}$  increased up to  $1700 \mu\text{g}/\text{m}^3$  at peak hours and  $970 \mu\text{g}/\text{m}^3$  off-peak hour at main bus stations in Addis Ababa.

### 4.2 Particulate Matter ( $PM_{2.5}$ ) (Fig. 7)

It is observed that bus stations have a great contribution for  $PM_{2.5}$  emission at all sampled stations and LRT has the smallest amount of particulate matter compared to bus, taxi and bus/taxi station both peak and off-peak hours.

### 4.3 Air Quality Index (AQI) (Fig. 8)

The average concentration of AQI at peak hours greater than off-peak hours. Minilik II square and Autobus Tera indicated that there is unhealthy AQI concentration is greater than an off-peak hour's air quality concentration (Table 4).

Air quality index (green = 0–50, yellow = 51–100, orange = 101–150, red = 151–200, purple = 201–300 and maroon  $\geq 300$ ). Bus and mixed (bus and taxi) stations have bad air concentrations at peak hour. Because bus stop shelter located at a busy road intersection and facing toward roadways, the concentration of PM and gaseous pollutants circulate inside the bus shelter. Most buses are the diesel engine and bus relatively consume more fuel and emit more pollutants than a taxi, heavy-duty vehicles pass on the roads where the station located. Taxi stations do not have shelter, unsheltered stops have less pollutant than sheltered stops. LRT station relatively has moderate air quality than bus or taxi stations. The average air quality at all stations falls under green, yellow, orange and red color code.

From Table 5: we understand that LRT station has good air quality and the bus station is unhealthy for sensitive groups. The air quality indicated that AQI increases at LRT, taxi, mixed and bus station from low to high, respectively. Industrial land-use with public transportation station has more pollutants than residential and commercial land-use.

### 4.4 Carbon Dioxide ( $CO_2$ ) (Fig. 9)

Average concentration of  $CO_2$  in ppm by type of station and location of the station. The highest  $CO_2$  occurred at the bus station and lowest in LRT station at Mexico station. Bus/taxi mixed station at Minilik II square observed that the 1307 ppm in average and 3500 ppm at maximum from bus and midi-bus vehicle stations.  $CO_2$  increases when there are high smoke from vehicles especially diesel engine and old

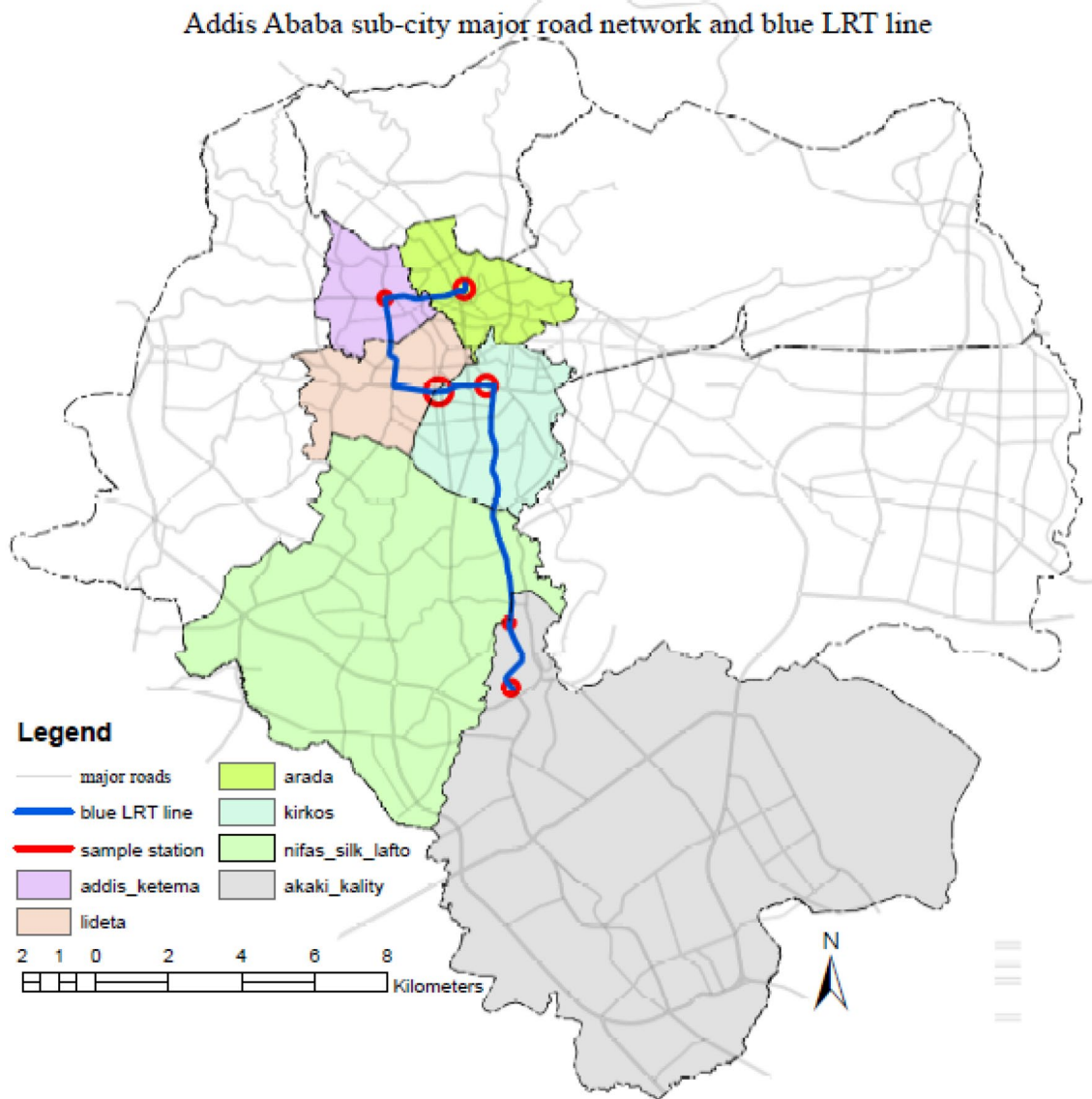
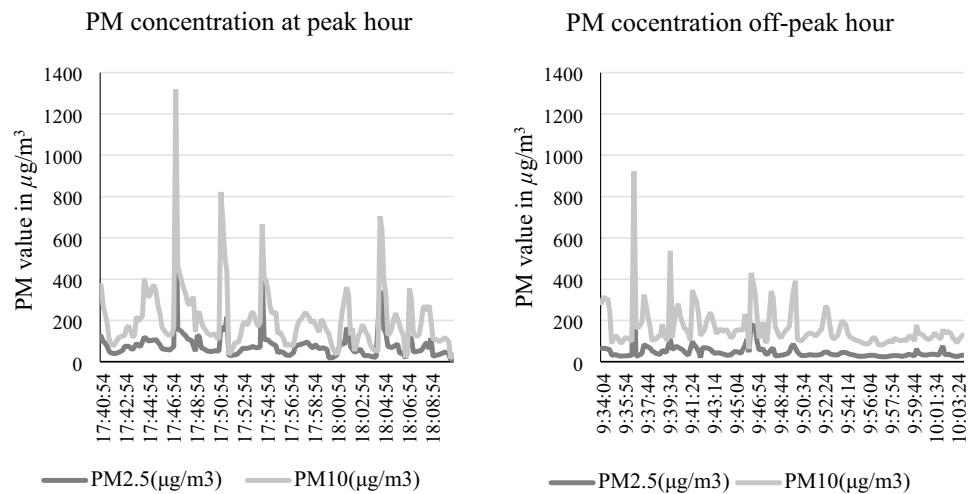


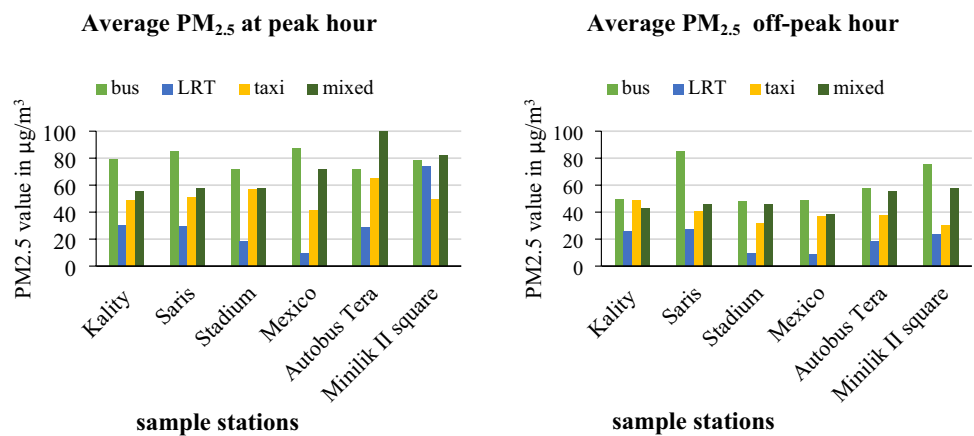
Fig. 5 Six major sampling stations at each sub-city North–South LRT line

Fig. 6 Particulate matter at peak hour and off-peak hour at bus stations

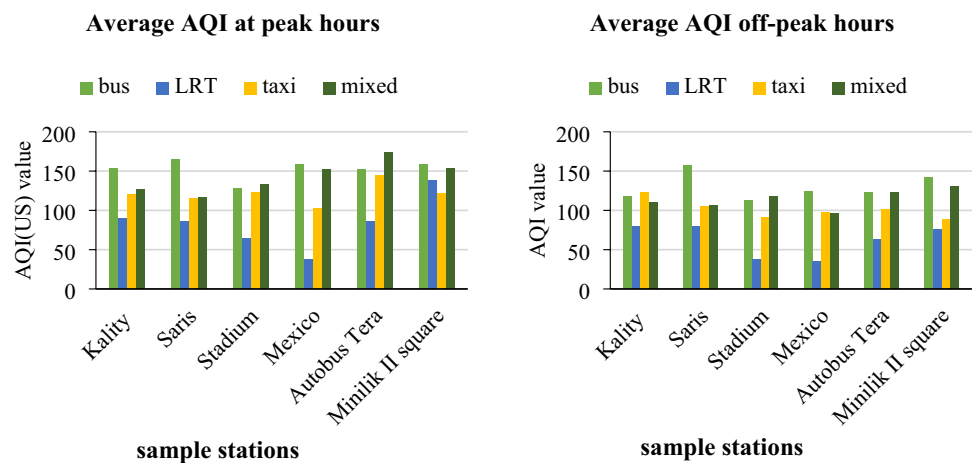




**Fig. 7** Average PM<sub>2.5</sub> concentration at peak and off-peak hour at the sampled station



**Fig. 8** Average AQI concentration at peak and off-peak hour at the sampled station



**Table 4** Average air quality index (AQI) at peak hours of six major sample stations

Stations	Bus	LRT	Taxi	Mixed (bus/taxi)
Kality	152.94 AQI	89.97 AQI	120.43 AQI	126.35 AQI
Saris	164.27 AQI	86.25 AQI	115.78 AQI	116.16 AQI
Stadium	127.42 AQI	63.84 AQI	123.04 AQI	133.29 AQI
Mexico	158.31 AQI	37.85 AQI	103.01 AQI	151.66 AQI
Autobus Tera	151.73 AQI	86.05 AQI	144.36 AQI	173.79 AQI
Minilik II square	158.34 AQI	138.32 AQI	121.86 AQI	153.56 AQI

**Table 5** Average air quality index (AQI) off-peak hours at six major sample stations

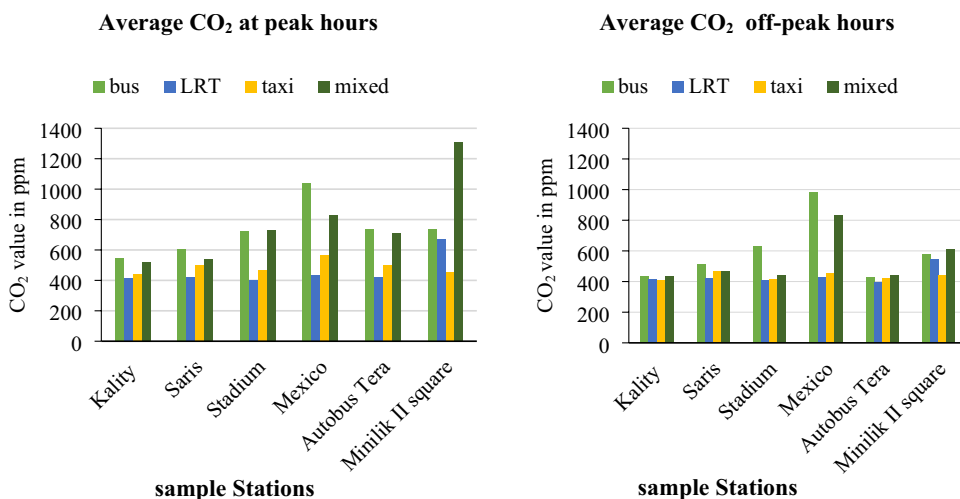
Station	Bus	LRT	Taxi	Mixed
Kality	117.44 AQI	79.92 AQI	123.15 AQI	110 AQI
Saris	156.71 AQI	79.98 AQI	105.07 AQI	106.17 AQI
Stadium	112.12 AQI	37.75 AQI	90.84 AQI	117.64 AQI
Mexico	123.93 AQI	34.39 AQI	97.13 AQI	96.53 AQI
Autobus Tera	122.4 AQI	63.26 AQI	101.43 AQI	122.24 AQI
Minilik II square	142.14 AQI	76 AQI	88.46 AQI	130.46 AQI

vehicles. Bus stations contributed the greatest concentration of CO<sub>2</sub> both at peak and off-peak hours.

### 4.5 Health Versus Air Quality and Station Characteristics

The relationship between health and air quality observed that when vehicles pollution became unhealthy (above 100AQI) at stations air quality-related health problems also increase. We understand from Table 6; relationship between air quality station design and health. When the air quality became worse, the incidence for air quality-related health problems

**Fig. 9** Average CO<sub>2</sub> concentration at peak and off-peak hour at the sample stations



**Table 6** Result of relationship between air quality, health and station design

Station name	Type of station	Incidences of air quality-related health prb	Air quality in 30 min			Station characteristics		
			Average PM <sub>2.5</sub>	Average CO <sub>2</sub>	Average AQI	Land use nearby station	Shelter availability and type	Vehicular traffic in speed (km/h)
Kality (88)	LRT	19	28.15	415.22	84.95	Industrial	Roof	33.6–43.0
	Bus	24	64.3	478.38	135.19	Industrial	Wall and roof	25.1–33.5
	Taxi	22	48.88	424.42	121.79	Industrial	No	33.6–43.0
	Bus/taxi	23	48.87	475.43	118.18	Industrial	Wall and roof	25.1–33.5
Saris (40)	LRT	8	28.51	419.96	83.12	Commercial	Roof	33.6–43.0
	Bus	13	84.88	557.67	160.49	Commercial	Wall and roof	25.1–33.5
	Taxi	9	45.73	484.4	110.4	Commercial	No	25.1–33.5
	Bus/taxi	10	51.64	502.09	111.16	Commercial	No	25.1–33.5
Stadium (51)	LRT	11	13.89	405.26	50.79	Mixed	Roof	25.1–33.5
	Bus	14	59.84	675.62	119.77	Mixed	No	25.1–33.5
	Taxi	13	44.06	439.02	106.94	Mixed	No	25.1–33.5
	Bus/taxi	13	51.47	584.78	125.46	Mixed	Wall and roof	25.1–33.5
Mexico (46)	LRT	10	8.72	428.88	36.11	Service	Roof	25.1–33.5
	Bus	13	75.11	1009.54	151.12	Service	Wall and roof	25.1–33.5
	Taxi	11	39.03	510.37	100.07	Commercial	No	25.1–33.5
	Bus/taxi	12	55.17	835.68	134.09	Commercial	Wall and roof	25.1–33.5
Autobus tera (41)	LRT	7	23.33	410.48	74.65	Commercial	Roof	25.1–33.5
	Bus	11	64.43	581.11	137.06	Commercial	Wall and roof	25.1–33.5
	Taxi	10	51.19	460.46	122.89	Commercial	No	25.1–33.5
	Bus/taxi	13	77.91	576.33	148.01	Commercial	Wall and roof	25.1–33.5
Minilik II square (58)	LRT	14	48.9	605.55	107.16	Service	Wall and roof	33.6–43.0
	Bus	15	76.63	656.32	150.24	Service	Wall and roof	25.1–33.5
	Taxi	13	39.76	444.13	105.16	Commercial	No	25.1–33.5
	Bus/taxi	16	69.81	960.34	147.01	Service	No	25.1–33.5
Total		324						

increased. There was also the land-use type had an accumulative impact on air quality as described from Table 6.

From the above Table 6: vehicular traffic speed and foot traffic were analyzed by level-of-service (LOS). Foot traffic in person per minute per feet and vehicular traffic in km/hr. it was analyzed by seven categories level of service from best to the worst (A up to F).

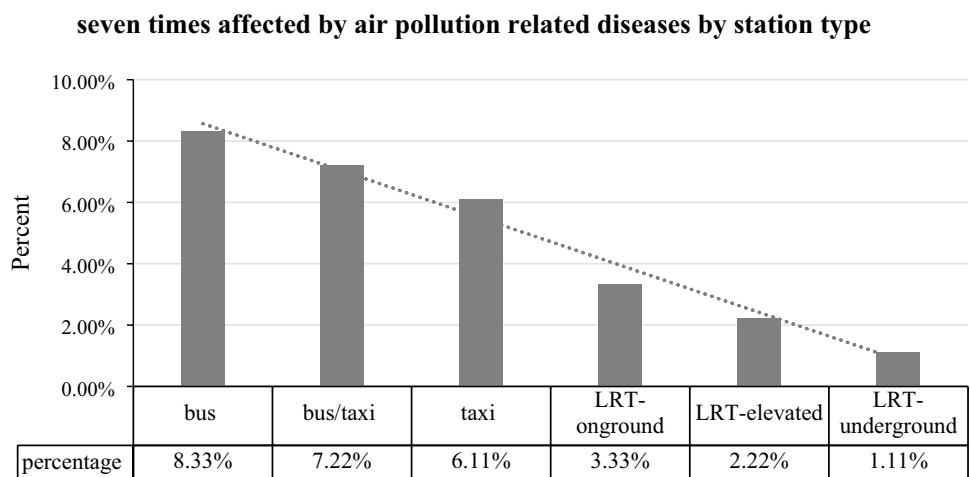
LOS	A	B	C	D	E	F
Vehicular traffic	Super light	Very light	Light	Medium	Heavy	Super heavy
Speed (km/h)	>67	54.5–67	43.1–54.4	33.6–43	25.1–33.5	0–25
Foot traffic (p/min/feet)	<6	6–7	8–10	11–15	>16	–

Average vehicular traffic volume both peak and off-peak hours are medium (33.6–43 km/h) and heavy (25.1–33.5 km/h), but most stations out of 24 sampled stations have very heavy (0–25 km/h) vehicular traffic movement. The result indicated, average foot traffic is also very heavy (> 16 p/min/30.48 cm) at peak hour and medium (8–10 p/min/30.48 cm) during off-peak hour based on the level of service.

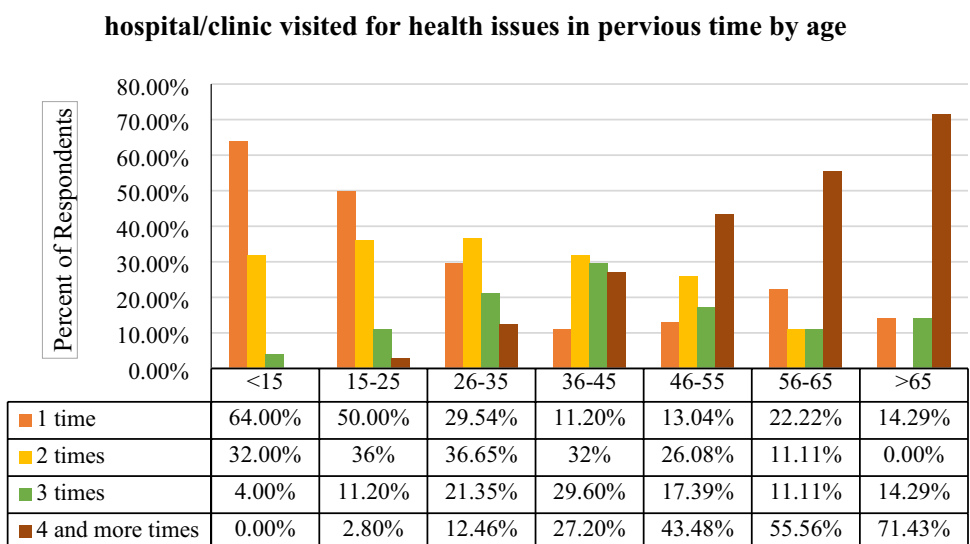
Respondents were exposed one up to seven types of air quality-related diseases. Out of 720 respondents, 44 were the maximum number of air pollution exposures. They were exposed to seven types of air quality-related diseases. From the graph, Fig. 10: the researcher concluded that bus stations have more exposure to air pollution than a taxi and Light Rail Transit (LRT) stations based on results and findings. This shows that vehicles used more than 15 years and repaired or serviced so many times.

From Fig. 11, elderly people have visited clinics/hospitals four and more times out of the seven total respondents above

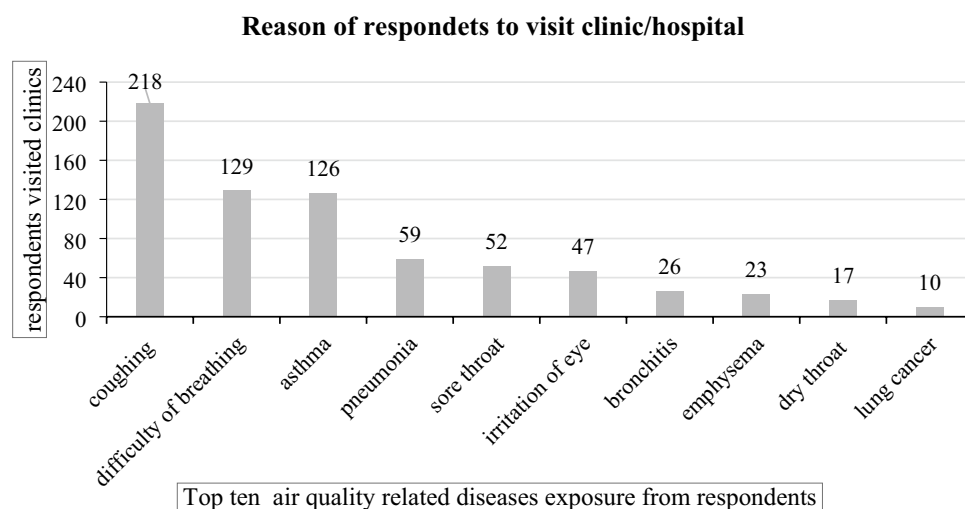
**Fig. 10** The greatest number of air quality-related diseases by station type understudy



**Fig. 11** Hospitals/clinic visited for health issues in the past time



**Fig. 12** Top ten air quality-related diseases from the respondents



**Table 7** Air quality index versus patients' reason to visit clinics/hospitals

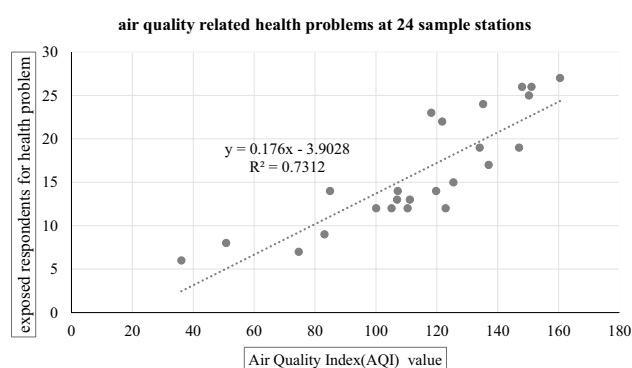
Air quality index (US) value	Reason to visit clinic/hospitals		Total	Percent of air quality-related diseases (%)	Percent of non-air quality-related diseases (%)
	Non air quality-related disease	Air quality-related disease			
0–50 (green)	20	10	30	33.33	66.67
51–100 (yellow)	69	51	120	42.50	57.50
101–150 (orange)	176	154	330	46.67	53.33
151–200 (red)	131	109	240	45.42	54.58
Total	396	324	720	45.00	55.00

age 65 (71.43%) of them were visited clinics by air quality-related diseases. This indicates that when age increases, the exposure to transport-related air pollution also increases (Fig. 12).

Out of 720 respondents 218 (30.28%) coughing, 129 (17.92%) difficulty of breathing, and 126 (17.5%) of asthma are exposed by transportation air pollution.

Out of 720, 339 (47.08%) exposed to coughing, asthma, the difficulty of breathing and emphysema. 118 (16.39%) exposed to a dry throat, 85 (11.8%) bronchitis, 53 (7.36%) difficulty of breathing. We could understand how air quality-related diseases affect human living and working in and around bus and taxi stations.

From Table 7, the air quality-related diseases increased due to air quality index increment from the table. This indicated that most of the residents in and around public transportation station in Addis Ababa have been exposing air quality-related diseases.



**Fig. 13** Number of incidence of air quality-related health problem and AQI

#### 4.6 Simple Regression Analysis of Air Quality-Related Diseases and Air Quality at Stations (Fig. 13)

The correlation between incidences of air quality-related health problems and air quality index (AQI) at 24 stations shows that  $R^2 = 73.12\%$  on average concentration, which is a strong positive relationships with each other's. The incidence of air quality-related health problems depends on location,

industrial, commercial and mixed land-use had a strong positive relationship with air quality index instruments.

The relationship between incidences of air quality-related health problems and air quality index (AQI) at Kality and Saris station had a strong positive relationship. Each station has LRT, taxi, bus/taxi and bus station indicated in the graph from the smallest to the largest, respectively. Air quality-related health incidence at Saris ( $R^2 = 0.954$ ) larger than Kality ( $R^2 = 0.939$ ). LRT station has the lowest AQI from all bus, taxi, and bus/taxi station. Thus, LRT station is good air quality.

The relationship between the incidence of air quality-related health problems and air quality index (AQI) has a strong positive relationship at Stadium and Mexico station. Each station has LRT, taxi, bus/taxi and bus station indicated in the graph from the smallest to the largest, respectively. Air quality-related health incidence at Mexico ( $R^2 = 0.904$ ) larger than Stadium ( $R^2 = 0.837$ ). This indicates that LRT has the least incidence for health problem but the bus has the highest incidence for air quality-related health problems.

LRT stations had low exposure for quality-related health problems at Autobus Ter. Bus, bus/taxi are the greatest contributors to the incidence of air quality-related health problems. LRT station at Minilik II square the only underground station and has poor air quality (particulate matter and  $\text{CO}_2$ ) at peak hour. Particulate matter and  $\text{CO}_2$  were greatest at an underground station like indoor air quality. The relationship between air quality and incidence of air quality-related diseases has a strong positive relationship. When the air quality index increases then the incidence of air quality-related health problem also increases.

## 5 Discussion

Based on the result, air quality at public transportation stations has bad air quality in Addis Ababa. As a result, respiratory diseases are worsened by poor transport-related air pollution. The study indicates that there is an unhealthy air condition at a public transportation station. Most motor vehicles are diesel engines, old and used more than 15 years (mini-bus, lorry). Within 30 min of observation, the average Air Quality Index (AQI) is above 150, which is unhealthy for everyone. Carbon dioxide ( $\text{CO}_2$ ) at the most station are below 700 ppm and two of them reached up to 1307 ppm on average at 30 min air quality measurement.

In view of the result of the measurement of air quality and health questionnaires, the connection between air quality-related medical conditions and air quality ( $\text{PM}_{2.5}$ ,  $\text{PM}_{10}$ , AQI,  $\text{CO}_2$ ) are solid straightforwardly relationship. The result indicated that when AQI increases then the exposure for air quality-related diseases increase. From 720 respondents, 324 (45%) have exposed to air quality-related diseases.

Station design has also impacted air quality. Near and far side station location related to roadway intersection observed that shelter type and availability impact the air pollution than mid-block stations. All bus shelters in the study area located on the sidewalk and by the road curve and oriented towards the roadway. This increased passengers' exposure to air quality-related diseases. Nine out of 24 sampled stations/stops have not sheltered. It is observed that Air-Visual indicated that bus stop with shelters has bad air quality than an unsheltered bus stop.

Vehicles pollution exposure is the major transport-related health impacts. Motor vehicles produce various pollutants which can cause health problems and environmental damage. Most importing vehicles are above 30 years old. From the result, there are 29.3% of vehicles above 30 years served (AARTB). This heavily increased pollution. Old vehicles release toxic into the atmosphere with severe health effects to those exposed to the pollutants in Addis Ababa especially who lives in Autobus Tera, Kality and Minilik II square cannot inhale clean air around the stations.

Commercial, industrial and administration land use attract more cars and people, on this land use (Air-Visual pro indicated that there is unclean air quality). Hence, on this attention on integrated land use with nature, the local adaptive tree should be planted on the median and sidewalk of the roads to filter air pollutants.

The main problems identified in passengers' interview were low frequency of bus and taxi services and hence long waiting times at stations exposed to vehicles emission near the road curve. Long waiting time and crowding results exposure for vehicles air pollution. These problems show an acute shortage of high occupancy vehicles. Inaccessible non-motorized transport road, fixed LRT line that does not address all parts in Addis Ababa. Single occupancy vehicles are too much on the roadways than public transportations that increase congestion and air pollution on the road. This increases negative health impact due to congestion and aged vehicles.

This study confirmed that transport-related air contamination adds to health impact, especially from respiratory and cardiovascular causes. It increases the threat of respiratory illnesses that are not identified with sensitivities. Long and momentary openness to air-suspended poisons has an alternate toxicological effect on human including respiratory and cardiovascular sicknesses. An investigation by Shenkute (2015) on the impact of diesel-fuel vehicles fumes smoke outflows on air contamination in Addis Ababa indicated that the overall rate for the 436 random sample diesel engine vehicles was 76%. This means that over 76% of the total sampled vehicles registered high smoke and particulate matter from vehicles. An extrapolation of this finding suggests that over three-quarters of the diesel engines fleet in Addis

Ababa produce exhaust smoke emissions above internationally accepted standards (US-EPA 1998).

The relationship between health and air quality observed that when vehicles pollution became unhealthy (above 100AQI) at stations air quality-related health problems also increased. Health and air quality have a strong positive correlation at the station. In addition to this, land-use, shelter type and availability affect air quality. It has poor air quality and exposure for air pollution-related diseases at industrial and commercial land-use. Shelter type is also affected air quality, wall and roof bus shelter at the road curve has poor air quality than unsheltered bus stops.

Respondents have been exposed for Asthma, emphysema, the difficulty of breathing, pneumonia, skin infections, and long haul persistent illnesses, for example, malignant growth. A few reports have uncovered the immediate relationship between openness to the helpless air quality and expanding illness and mortality generally because of cardiovascular and respiratory sicknesses (Ghorani-Azam et al. 2016). Transport air contamination is considered as the major biological danger factor in the occurrence and movement of certain infections, for example, asthma, cellular breakdown in the lungs, emphysema, pneumonia, sore throat and nausea. Regarding this, the results indicated that exposure to transportation air pollution peoples living/working on and proximity to the public transportation stations have been increasing. Out of 720 respondents working/living proximity to the major roads 324 (45%) were exposed for breathing and cardiovascular diseases.

This study indicated that transport-related air pollution contributes to an increased risk of health, particularly from respiratory. It increases the risk of breathing symptoms and diseases that are not related to allergies. Long and short-term exposure to air-suspended toxicants on human including breathing and cardiovascular diseases. The 2012 Vehicular Smog-less Air for Ethiopia (V-SAFE) baseline report found that 50% of the Addis Ababa gasoline engine vehicles fleet produced 90% of the HC and CO<sub>2</sub> emissions (Benjaminsin and Shenkute 2012). Moreover, a similar report affirmed that the concentration of PM levels in the city surrounding air was multiple times on normal higher than the equivalent USA and WHO standards.

## 6 Conclusion

Generally, this study has tried to quantify and describe air quality particularly (PM<sub>2.5</sub>, PM<sub>10</sub>, CO<sub>2</sub> and AQI) at public transportation stations, its health impact and relationship between air quality, and station design in Addis Ababa.

Thus, LRT, bus, taxi stations and the type of land-use (industry, and cooking firewood in residential area), as well as the nature of station design, construction, dust along road shave an overall impact on air quality at transportation stations.

Based on the finding, air quality at public transportation stations in Addis Ababa is unhealthy, above a mean of 65 µg/m<sup>3</sup> PM<sub>2.5</sub> and 150 AQI concentrations at bus and taxi stations during peak hours. There are many old vehicles in Addis Ababa which contribute significantly to the high levels of pollutants. The concentration of particulate matter (PM<sub>2.5</sub>) at public transportation stations in Addis Ababa is greater than WHO limits (25 µg/m<sup>3</sup>). This result caused breathing and cardiovascular diseases a person who lives/works in and around the transportation stations.

LRT stations have a mean below 25 µg/m<sup>3</sup> PM<sub>2.5</sub> and 70 AQI concentration at peak hours. It was also observed that air quality is good at LRT stations than bus or taxi stations.

## 7 Recommendation

The finding of this research indicated that there is very poor air quality at public transportation stations. Bus/taxi passengers frequently spend 25–45 min or more waiting for a bus/taxi which is exposing them to pollutants at stations. The air quality index showed that bus stop located near side the intersection has more pollutants than far side and mid-block. Therefore, moving bus stops away from busy intersections would noticeably reduce the number of pollutants and exposure during peak hours.

LRT is the better option for transportation to reach on time without delay primarily pollution reduction. Hence, LRT should be extended to uncovered main roads of Addis Ababa to reduce congestion and transport-related air pollution. Transport-related air contamination is affecting human health. Policy need to encourage the introduction of the zero emission vehicles and elective transportations.

There is a research gap related to air quality at public transportation stations in Addis Ababa. No regulation and standards on air pollution emission level and its health impact and poor implementation in the transport sector. Moreover, the concentration of CO, volatile organic compounds (VOCs), SO<sub>2</sub>, NO<sub>x</sub> and O<sub>3</sub> should be studied during both peak and off-peak hour. Identify the ambient concentration of air pollutants emitted from transportation and other sources to reduce its concentration separately.

## Declarations

**Conflict of interest** All authors declare that they have no conflict of interest.

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